6

Science for Tomorrow's World

8

THE MACMILLAN SCIENCE SERIES

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J. DARRELL BARNARD
SCIENCE EDUCATION

CELIA STENDLER
CHILD DEVELOPMENT AND ELEMENTARY EDUCATION

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UNDER THE EDITORSHIP OF

SIDNEY SELTZER

SCIENCE FOR TOMORROW'S WORLD: 1, 2, 3, 4, 5, 6

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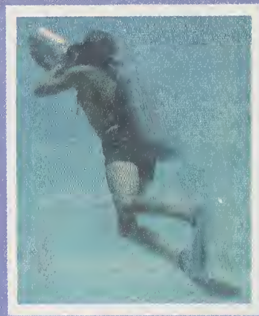



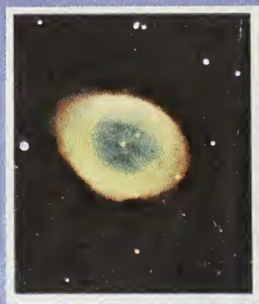

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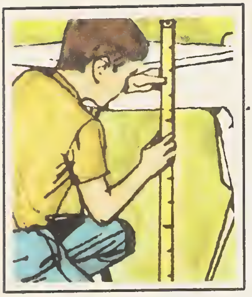


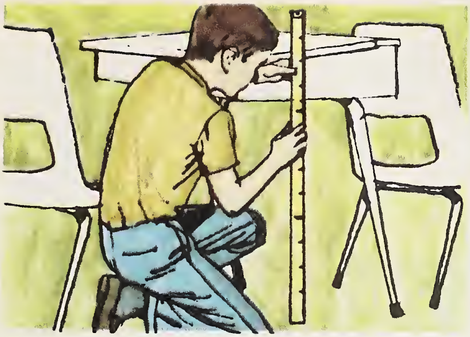
Men have been concerned with measurement for thousands of years. Through the centuries, systems of measurement were devised and improved, leading to the systems that we use today. There is still room for improvement. Today, as in the past, measurement is vital to almost all scientific investigation.

Recording Measurements

From the beginning of a new life the important measurements of time and size are recorded.

Measurements are used to build new ideas. Measurements also play an important part in our present knowledge about the world in which we live. Measuring things is often a daily part of a scientist's work. All scientists, no matter in what area of science they work—chemistry, biology, physics, geology—must be very careful and accurate. To be accurate so that other scientists can rely on their reports, scientists must use tools for measurement. Why is this so important?

Mr. and Mrs. Jasper Smith
ANNOUNCE THE ARRIVAL OF
Robert Louis Smith
ON **January 2, 1965**
WEIGHT **7 pounds 3 ounces** HEIGHT **19½ inches**

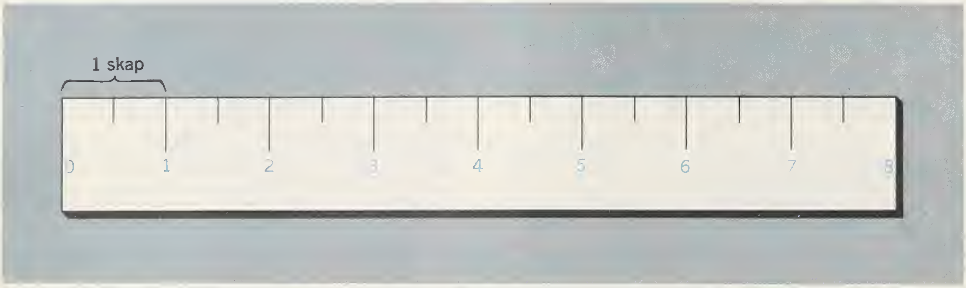
How high is your desk? To find out, measure the distance from the floor to the top of your desk. Make a record of your measurement, but do not show it to anyone. Now ask one of your classmates to measure the height of your desk. Ask him to write down his answer, but not to show it to anyone. Do the same with a second classmate and then a third.

Now compare the measurements. They probably will vary slightly. You may have recorded the height of your desk to the nearest half inch. Perhaps one classmate measured to the nearest inch. Maybe another classmate measured to the nearest quarter inch. Which measurement is correct? What if one person reports a measurement that is several inches different from all the others? What might have happened?

If the measurements were made carefully, each person may have obtained the "right" answer. For some purposes it is necessary to measure things to the nearest inch. Sometimes it is necessary to measure something to the nearest yard. At other times the nearest mile is enough. For example, guess how far it is from your house to your school. It certainly is not useful to know this distance to the nearest inch. If you live far away, the measurement to the nearest half mile tells you all you want to know.

On the other hand, if you want to know how much you have grown during the summer, you would need a measurement even more exact than one to the nearest inch. You would probably measure your height to the nearest quarter inch.

What kind of thing would you measure to the nearest foot? The nearest mile? The nearest eighth of an inch? The nearest 100 miles? The nearest million miles?



You too can make up units of measurement. The ruler above is marked in units called *skaps*. What problems would arise if everyone made up his own units of measurement?

Standard Units

The picture shows a ruler you have never seen before. It is marked off in units called *skaps*. Make a ruler like this and measure the width of your desk. Measure the width as carefully as possible. How many skaps wide is your desk? Next measure the width of your hand using the same ruler. How many skaps wide is your hand?

Now, imagine that you are ordering a pair of shoes by mail. You measure your foot and discover it is four skaps wide at the widest part and eleven skaps long. You include these facts in your order. The shoe manufacturer receives your instructions. But, of course, he has no idea what size shoe to send you. He does not know the size of a skap.

Nobody in the world uses a skap as a unit of measure. The authors of this book made it up. You too can make up a unit to measure length. You can make the unit as long as you wish and you can name it anything you wish. You can make very careful measurements using your own units. You can even make up a measuring system with many new units based on your first unit. For example, you could say that four skaps are equal to one *von,* fifteen vons are equal to one *jal,* and six thousand jals are equal to one *squeed.* You could even find out how many squeeds it is, say, from San Francisco to Denver. But no one would know what you were talking about!

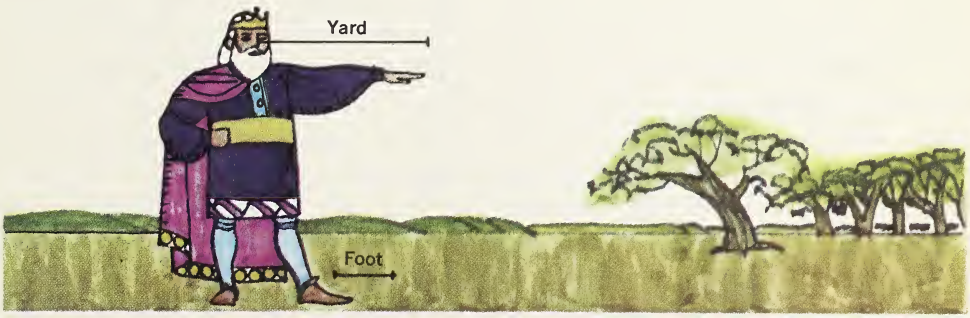
Anyone listening to you describe something as "fourteen jals long" would feel as confused as the shoe manufacturer who did not know the length of a skap.

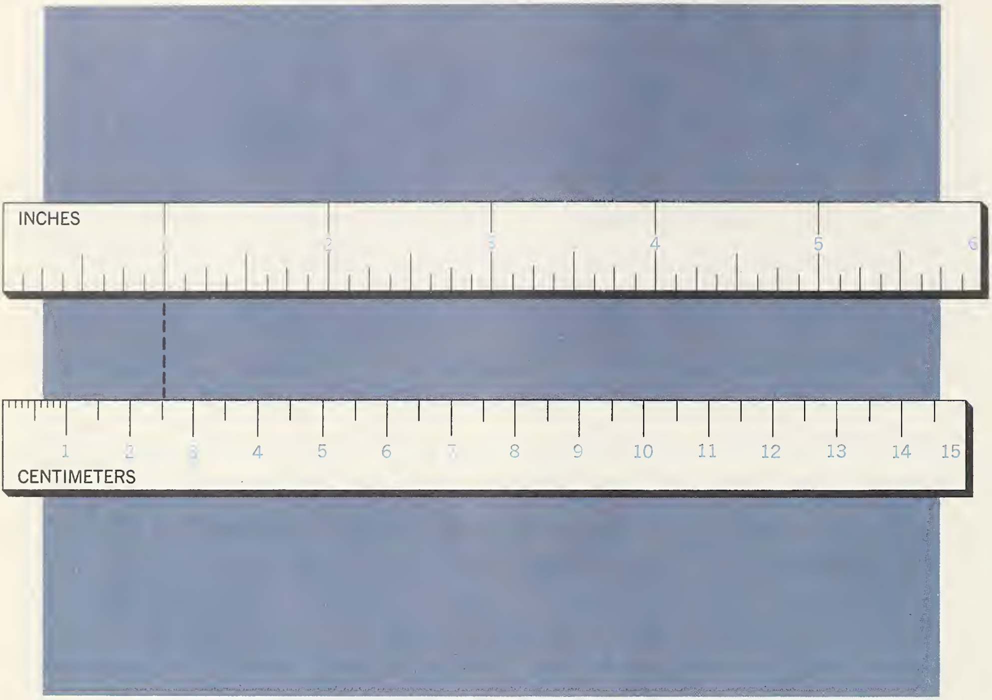
In order to make sure that other people know what we mean when we report our measurements, we must all agree to use certain units of measure. We must agree on the exact value of these units. Units that everyone agrees to use are called **standard units.**

We all know how long an inch, a foot, a yard, and a mile are. But there is nothing in nature to tell us the *exact* value of the standard units we use. From where, then, did these units of measurement come? They were decided on by men. A "yard" might have originally been the distance from the nose of a certain king to the tip of his outstretched arm. Perhaps a "foot" measured the length of one of the king's feet. But kings' feet come in different sizes, and measurements must be exact. Whether a person tries to fit shirts or to fit automobile tires, he must have exact measurements. A standard unit must be used to avoid confusion.

If a large number of people use the same unit of measurement, the unit becomes a standard unit. Large numbers of people use the inch, the foot, the yard, and the mile to measure length. They use the ounce and the pound to measure weight. They use degrees Fahrenheit to measure temperature. These units are in the **English system** of standard units.

There are more people, however, who use a different system of standard units. They use the **metric system.** They use the centimeter, the meter, and the kilometer to measure length. They use the gram and the kilogram to measure the **mass** of objects—that is, the amount of **matter** in them. And they use degrees Centigrade to measure temperature. Scientists use the metric system. Can you find out why?





Changing from One System to Another

Here are two rulers. One looks familiar to you; the other may not. Yet the unfamiliar one is used in almost all non-English-speaking countries. You can use either one, of course, to measure your height. Perhaps you are 58 inches tall, and this fact is noted on your school record for this year. If you were a student in Italy, your school record would say that your height is 147 centimeters. This may sound as if you would be taller in Italy, but remember that the standard units are different from the ones we use. You can change measurements in one standard unit into measurements in another. In the example above, you saw that 58 inches is approximately the same as 147 centimeters.

To make it easier for scientists to understand each other, England decided in 1965 that she will use the metric, rather than the English, system of measurement.

In the metric system, larger units are formed from smaller ones in a series of regular steps. Each unit is ten times the size of the next smaller unit. The names of the units are formed by adding a prefix to the basic unit. In measuring length, the basic unit is the meter. The prefix tells how many meters or how many parts of a meter the unit contains.

Milli is a prefix that means one one-thousandth part of, or 1/1000. *Centi* means one one-hundredth part of, or 1/100. What does *deci* mean? *Deca* means ten and *hecto* means one hundred. What does *kilo* mean?

One meter is equal to 39.37 inches. How many inches are in a *deca*meter? A *hecto*meter? A *kilo*meter? To answer these questions, you must change a measurement in one system of standard units into a measurement in another system. You change units from the metric system into units from the English system.

The table on the right below shows how to change units from the English system into units from the metric system.

The standard unit of mass in the metric system is the *gram*. A nickel, for example, is an object that has a mass of about 5 grams.

1 *kilo*meter	=	1,000 meters (10 *hecto*meters)
1 *hecto*meter	=	100 meters (10 *deca*meters)
1 *deca*meter	=	10 meters (10 meters)
1 meter	=	1 meter (10 *deci*meters)
1 *deci*meter	=	1/10 meter (10 *centi*meters)
1 *centi*meter	=	1/100 meter (10 *milli*meters)
1 *milli*meter	=	1/1000 meter

English System		*Metric System*
1 inch	=	2.54 centimeters
1 foot	=	0.305 meter
1 yard	=	0.914 meter
1 mile	=	1.61 kilometers

Natural Units

The metric system was established in France in the 1790's. Later it was adopted by most other countries. The length of the meter is not based on any object found in nature. It is the distance between two scratches on a platinum bar kept in the International Bureau of Weights and Measures in France. Standards are established in each country, and these standards are compared to the one in France. The gram is the mass of a particular cylinder of platinum that is also located in the International Bureau of Weights and Measures. The meter and the gram are, thus, not natural units. They are units that were decided on by man.

The units that we use to measure the day and the year come close to being natural units. One year is about the time it takes the earth to go around the sun—365 days. One day is the time it takes the earth to rotate once on its axis.

However, there is nothing natural about the way the day is divided. The day is divided into 24 hours. Each hour is divided into 60 minutes. Each minute is divided into 60 seconds. How many seconds are there in one day? Both the English system and the metric system use the same standard units to measure time.

The cylinder housed under three glass jars is the International Kilogram. Why do you think it is protected in the manner shown above?

Unchanging Measures

Once standard units have been established, it may seem that all problems of measurement have been solved. This, however, is not true. Do the following experiments to find out what kinds of problems have not been solved.

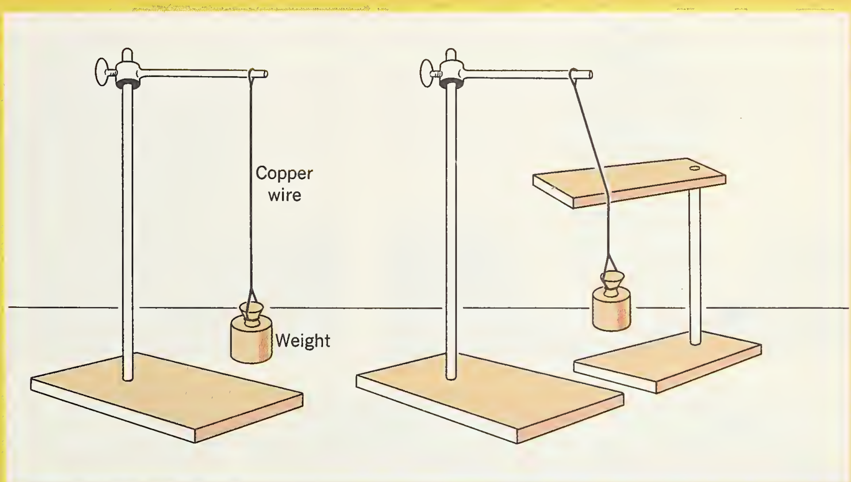
Does the Length of a Wire Change?

What You Will Need

a weight	candle or	ruler
copper wire	alcohol lamp	

How You Can Find Out

1. Tie the weight to the end of the copper wire.
2. Tie the other end of the wire to a firm support, as shown.
3. Let the weight hang down over a second support.
4. Measure the distance between the weight and the point where the wire curves over the second support.
5. Heat the wire for a minute or two with a candle or an alcohol lamp. Notice what happens to the weight.
6. Measure the distance from the weight to the second support again.



Questions to Think About

1. What happened when the wire was heated?
2. Can you guess why this happened?
3. What does this experiment show?

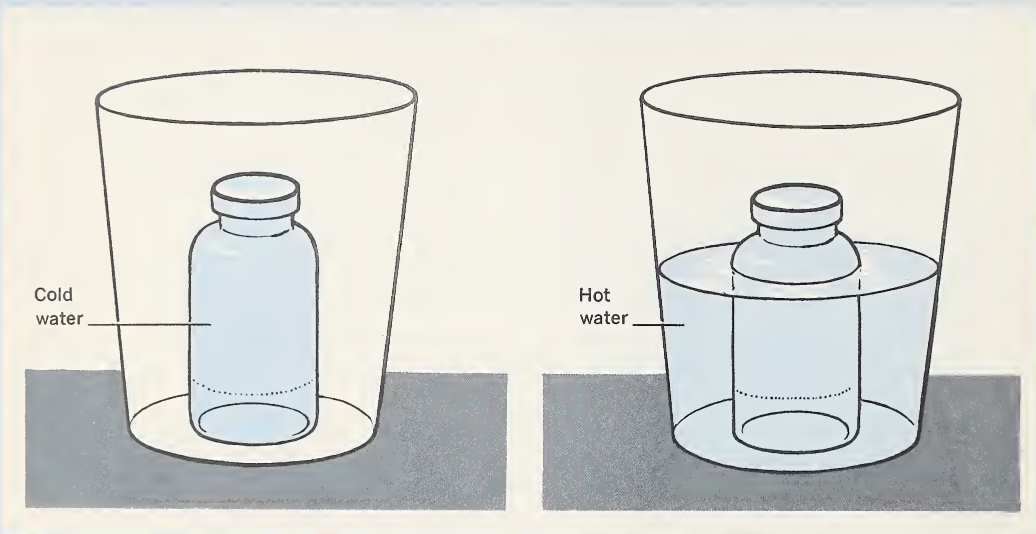
Can the Amount of Space Occupied by a Liquid Change?

What You Will Need

pail   narrow-necked quart jar   water

How You Can Find Out

1. Put a narrow-necked jar in a pail.
2. Fill the jar to the very brim with cold water.
3. Put enough hot water in the pail to go about three-quarters of the way up the outside of the jar.



Questions to Think About

1. What happens to the water in the jar?
2. Can you guess why this happened?
3. What does this experiment show?

First the water took up one quart of space. After it was warmed, it took up more than one quart of space. The amount of space something occupies is its **volume.** The volume of water changed when the temperature changed.

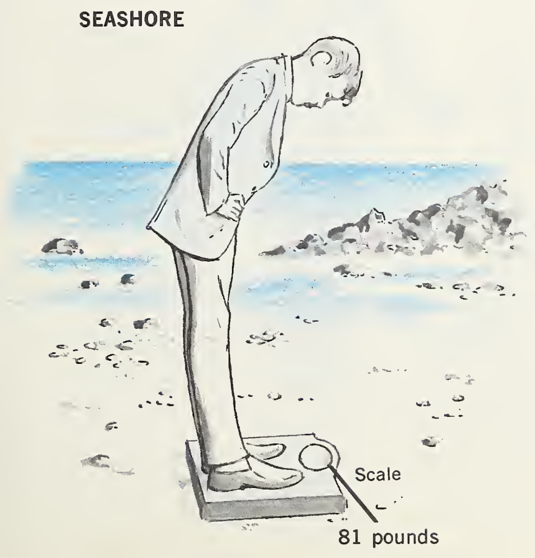
Gravity and Weight

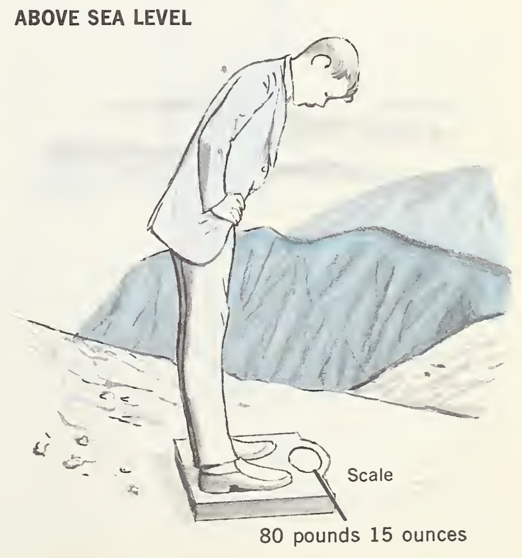
The level of the surface of the sea is referred to as **sea level.** You weigh a certain amount at sea level. If you were on the top of a high mountain, you would weigh slightly less than you do at sea level.

Why does your weight change? The answer is that your weight depends on the *attraction* between you and the earth. **Gravity** is the *pull* toward the center of the earth. The closer you are to the center of the earth, the greater the pull. The farther away you go, the weaker the pull. You weigh more on a bathroom scale when there is a greater pull. You weigh more in a deep mine because you are closer to the center of the earth, and the pull on you is greater. You weigh less on a high mountain because you are farther from the earth's center than you are at sea level. Where do you think a man would weigh more, in an airplane or in a submarine? Why?

The length, volume, and weight of objects are not always the same. They depend on other things, such as temperature and distance from the center of the earth.

When scientists measure, they use the standard units of measurement, and they measure everything under the same conditions.





Matter and Mass

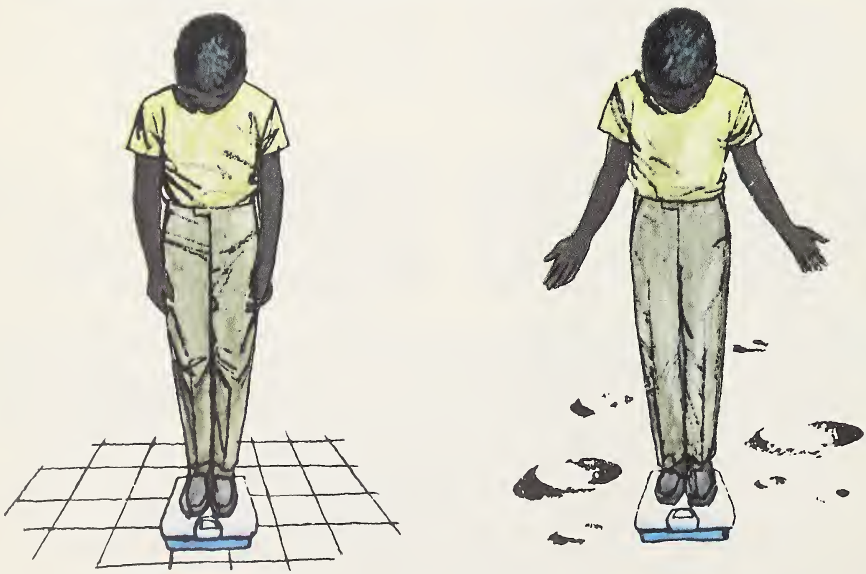
Sometimes a scientist wants to measure how much material, or matter, makes up an object. What unit of measurement can he use? He cannot use length, because, as you saw in your experiment with the copper wire, the length of some objects changes when the temperature changes. He cannot use volume, because, as you saw when you experimented with water, the volume of water changes when the temperature changes. He cannot use weight, since the weight of an object changes according to how high up it is.

What unit of measurement can the scientist use? Scientists have solved this problem by using the unit of measure called *mass*. Mass is the amount of matter in an object.

Although your weight depends on where you are standing, you are still you! You have the same arms, the same legs, the same head, and the same body on the top of the mountain as you do at the bottom. The weight of your body has changed, but your body has not.

Think about an astronaut in space. The farther away he is from the earth,

Would you weigh the same on earth as you would on the moon? Would you have the same mass? How do weight and mass differ? Can you tell if your mass ever changes?



the less he weighs. He is still, however, the same astronaut. The reason he weighs less is not that he took off his space suit and not that he suddenly got thinner. He weighs less because he is farther from the center of the earth. But although his weight has changed, his mass has *not* changed. Remember that mass is the quantity of matter in an object. What the astronaut is made up of, his mass, has not changed. All that has changed is the attraction between him and the earth.

Scientists use mass as a unit of measurement because it does not depend on where measurement is made.

In order to make sure that a measurement is accurate, there has to be something with which to compare that measurement. The mass of a kilogram is that of a platinum cylinder also located in France.

Relationships

It is often possible to solve a problem about measuring by finding only one quantity. For example, you might want to find the distance from one end of your classroom to the other. You might want to measure the time it takes to go from one place to another. Or you might want to find out how fast a car is going.

Instruments help you to solve such problems. What instrument would you use to measure the length of your classroom? What instrument would you use to measure the time it takes to go from one place to another? What instrument tells you how fast a car is going?

However, there are many problems in science that can be solved only if you know how distance, time, and speed are related. For example, most people can walk about 3 miles in 1 hour. Suppose that you were told that Harry walked from Centerville to Pine Ridge in 4 hours. Suppose that you were then asked, "Did Harry walk faster or slower than most people?" You could not answer this question unless you knew another quantity—the distance between the two towns. If you knew that the towns were 8 miles apart and that it took Harry 4 hours to make the trip, would you say he was a fast walker?

To solve this problem, the first thing you want to know is how many miles an hour Harry walks. You want to know this so that you can compare it to how many miles an hour most people walk. The first step is to divide the distance (8 miles) by the time it took Harry (4 hours) to walk the distance.

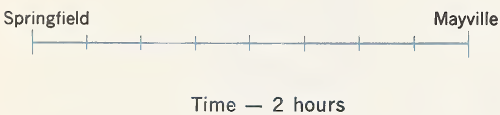
$$\frac{8 \text{ miles}}{4 \text{ hours}} = 2 \text{ miles an hour}$$

The next step is to compare. Since you know that most people walk 3 miles an hour, you now know that Harry walks slower than most people.

Because you knew the distance between the two places and the time it took Harry to walk that distance, you could find his *speed*. Speed is the time it takes to go a certain distance. Suppose that the distance between Paul's house and Paul's school is 4 miles. It takes him 1 hour to walk to school. How fast is Paul walking? You can easily determine that the speed at which he is walking is 4 miles an hour.

Can you solve these two problems?

1. The distance between Springfield and Mayville is 80 miles. A car travels 2 hours to go from Springfield to Mayville. What is the speed of the car? Here is a picture of the problem.



2. The air distance between New York City and San Francisco, California, is about 2,500 miles. A jet airplane takes about 5½ hours to fly this distance. How fast does the plane travel? Can you make a picture of this problem?

To find the answers to these problems, you divided the distance by the time. To explain how you solved these problems, you might say, "If you want to find the speed, divide the distance by the time." Or:

$$\text{speed} = \frac{\text{distance}}{\text{time}}$$

This way of writing what you mean is called a **formula.** A formula explains ideas in a shorter way.

You have used formulas before. If you wanted to say that 300 added to 300 is 600, you wrote:

$$300 + 300 = 600$$

If you wanted to say that 300 multiplied by 2 is 600, you wrote:

$$300 \times 2 = 600$$

If you wanted to say that half of 600 is 300, you wrote:

$$\frac{600}{2} = 300$$

These are different ways of showing the same relationship. You can show the same relationship in different ways with distance, speed, and time also. You can say that if it takes a plane 2

hours to fly 600 miles, then the plane is flying at a speed of 300 miles an hour:

$$\frac{600 \text{ miles}}{2 \text{ hours}} = 300 \text{ miles per hour}$$

You can say that if the speed of an airplane is 300 miles an hour and it traveled for 2 hours, the distance it traveled was 600 miles. You would write:

$$300 \text{ miles per hour} \times 2 \text{ hours} = 600 \text{ miles}$$

Both statements say the same thing. If you can say that

$$\text{speed} = \frac{\text{distance}}{\text{time}}$$

then you can also say that

$$\text{distance} = \text{speed} \times \text{time}$$

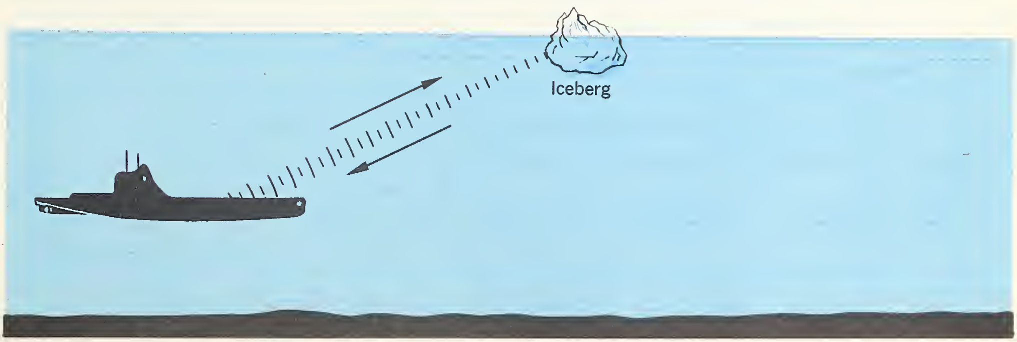
Can you find a third way of showing this relationship? How is time related to the other two quantities? Finish this statement on a separate piece of paper:

$$\text{time} = \frac{?}{?}$$

Using Relationships

We use the formulas that tell how to find distance, speed, and time in very important ways. Suppose you were on an atomic submarine and wanted to measure the distance from the submarine to an iceberg. It is easy to see that this distance cannot be measured with a yardstick. But you can use one of the formulas. You know the speed of sound. Sound travels about ⅘ mile in one second in water. You can send out a sound to the iceberg. When the sound reaches the iceberg, it bounces back as an echo. You can time how long it takes the sound to go to the iceberg and come back to the submarine. There is an instrument called **sonar** (SOH-nahr)

Use the picture to tell how sound is used to find the distance to an iceberg.



on a submarine. Sonar measures how long it takes the sound to make the round trip to the iceberg. By using sonar, you can find that it takes 20 seconds for the round trip. Now you know two quantities—speed and time.

Here is the formula to use:

$$\text{distance} = \text{speed} \times \text{time}$$

You multiply the speed of sound ($\frac{4}{5}$ mile a second) by the time it takes the sound to go out and come back (20 seconds).

$$\text{distance} = \text{speed} \times \text{time}$$
$$\text{distance} = \tfrac{4}{5} \times 20$$
$$\text{distance} = 16 \text{ miles}$$

But the problem is still not solved. It is 16 miles for a round trip, and you want to know how far away the iceberg is, or how far the sound has to go one way to reach the iceberg. How can you find the answer?

Making Graphs

Once you know how to draw and how to read a graph, you can see many relationships at a glance. A graph can show how distance, time, and speed are related. A graph is very helpful, because it saves time. Instead of having to read many pages of facts, we can see them all on one graph.

Drawing the Graph

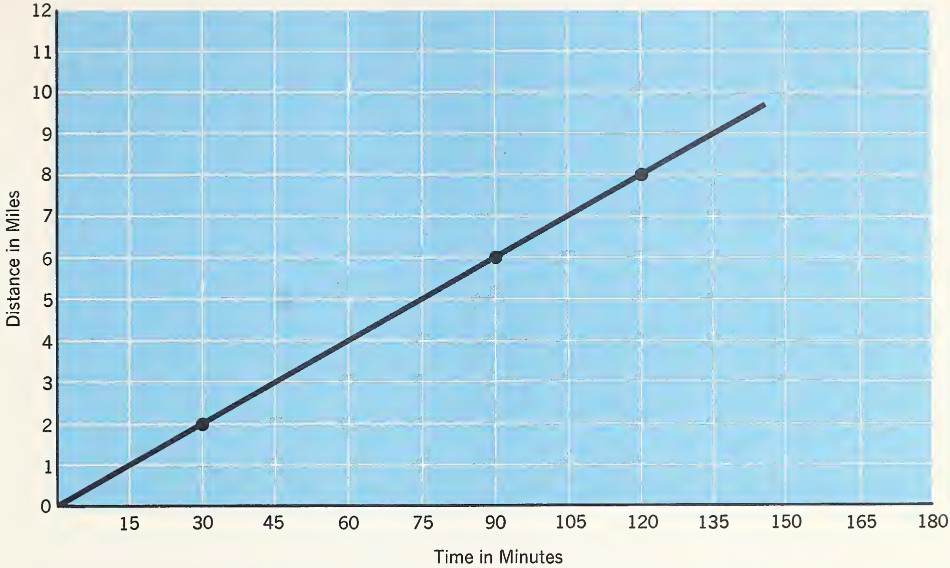
The first thing you need to draw a graph is paper that is divided into many small boxes. You can use the horizontal lines to represent one quantity and the vertical lines to represent another. Look at the graph. The bottom horizontal line is labeled "Time in Minutes" and represents 180 minutes. Each division of the line stands for 15 minutes. If you move one unit along the horizontal line, you have represented 15 minutes. The vertical line is labeled "Distance in Miles" and represents 12 miles. Each division stands for 1 mile. If you move one unit up the vertical line, you have represented a distance of one mile.

The graph you looked at shows the relationship between the distance that Henry walks and the time it takes him to walk it. You draw, or *plot,* the graph by putting in the information you have.

Suppose you know that:

1. At the end of 30 minutes, Henry walked 2 miles.
2. At the end of 90 minutes Henry walked 6 miles.
3. At the end of 120 minutes, Henry walked 8 miles.

The first thing to do is to find the spot that stands for 30 minutes. Since



the horizontal line stands for time in minutes, you would look along this line. Start at 0 and move across the line until you come to the line that stands for 30 minutes. Put your pencil on this line. Since the vertical line stands for distance, you have to move your pencil up the 30-minute line until you come to the line that stands for 2 miles. Put your first dot here. Check the graph to see if you found the right spot.

To find where the second dot goes, do the same thing that you did for the first dot. Find the line that stands for 90 minutes, move up the line until you come to the line that stands for 6 miles, and put the dot there. Check the graph to see if you found the right spot.

Plot the third dot in the same way. Now draw a line that connects the three dots. The graph is finished.

Reading a Graph

Now that you know how to plot a graph, it will be easy for you to learn how to read it. If you know that Henry walked for 30 minutes, can you tell how far he walked? Put your pencil on the line that stands for 30 minutes and move up that line until you find the spot where the graph touches that line. You see that it touches at 2 miles. Henry walked 2 miles. Now answer the questions on the next page.

1. How far did Henry walk in 90 minutes?

2. How far did Henry walk in 120 minutes?

3. How far did Henry walk in 135 minutes?

Suppose you knew that Henry walked 2 miles and you wanted to know how long it took him. You would put your pencil on the line that stands for 2 miles and move across it until you found the spot where the graph touches that line. You would see that it touches at 30 minutes. Therefore, it took Henry 30 minutes to walk 2 miles. If Henry continued at the same rate:

1. How long would it take Henry to walk 6 miles?

2. How long would it take Henry to walk 7 miles?

3. How long would it take Henry to walk 10 miles?

The graph that you see at the bottom of this page shows the relationship between time and distance for Warren's walk.

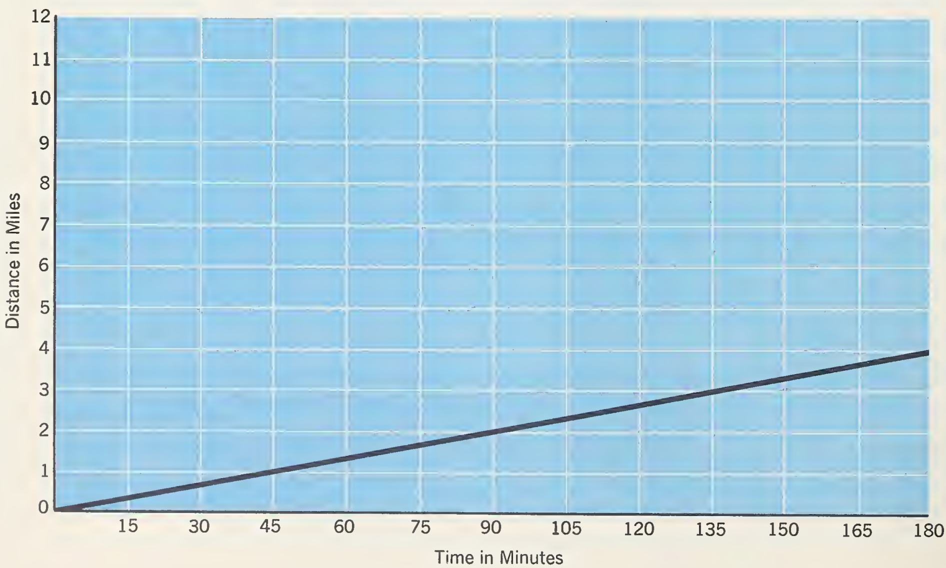
Use the graph to answer these questions:

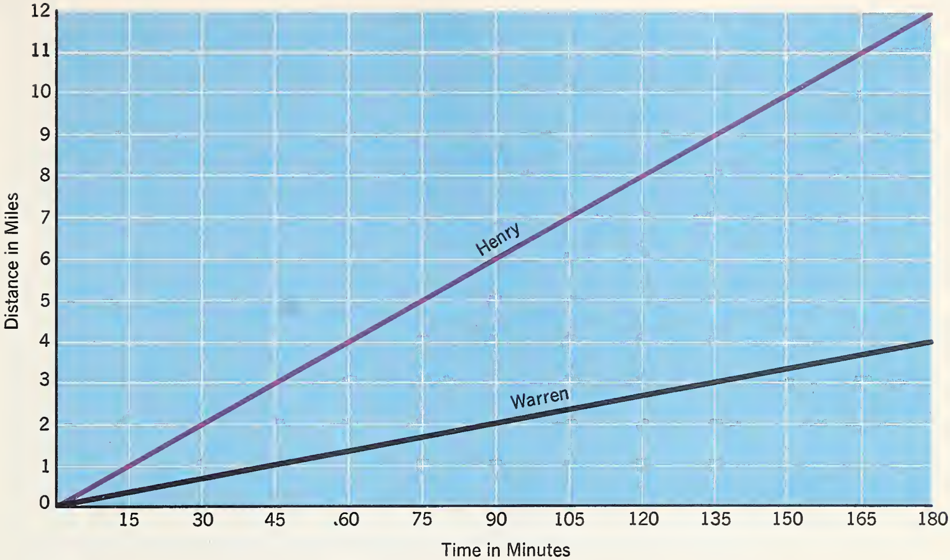
1. How many minutes did it take Warren to walk 1 mile?

2. How many minutes did it take him to walk 3 miles?

3. How far did Warren walk in 90 minutes?

4. How far did he walk in 3 hours, or 180 minutes?





Look at the graph above. This time the two walks are shown on the same graph. Use it to answer these questions:

1. When Henry had walked 3 miles, how far had Warren walked?
2. When Henry had walked 9 miles, how far had Warren walked?
3. How far had each boy walked in 60 minutes?
4. Which boy walked faster?

Whenever you talk about the relationship between distance and time, you are talking about speed.

The red and green lines on this graph tell about relationships between distance and time for Henry and Warren. They must, then, tell us something about the speed of each boy. You can use the formula

$$\text{speed} = \frac{\text{distance}}{\text{time}}$$

to find how fast they walked.

The graph tells you something else. Notice that Henry's line is steeper than Warren's. Remember, Henry is walking faster. That means he is covering more distance than Warren in the same time. To find out where to put your dot for Henry's position at the end of a certain time, you had to go up higher on the vertical line than you did for Warren. If you go *over* the same distance but *up* farther to put your dots, then your line will be steeper. A steeper line shows a higher speed.

Using What You Have Learned

1. Graphs show relationships of quantities other than time and distance. The graph explained below shows the relationship between the amount of fuel in a car tank and time.

A man is driving his car across the desert at a steady speed. He began with a full tank of 16 gallons of gasoline. He uses up 1 gallon of gas every 20 minutes.

Plot a graph to show this relationship. Write the numbers from 1 to 16 along the vertical edge of the graph paper. These numbers stand for the amount of fuel in gallons. Along the horizontal edge, write the numbers 20, 40, 60, 80, and so on until there are 16 numbers. These numbers stand for minutes. You know that the man uses up 1 gallon of gas every 20 minutes. Where would you put the dots to show how much gasoline he used up in 20 minutes, in 40 minutes, and in 60 minutes? Now draw a line to connect the dots. Can you find out by reading this graph how much gasoline the man used in an hour and a half?

2. Moving objects do not always travel at the same speed; they may speed up or slow down. When an object changes its speed, we say that it **accelerates** (ak-SEL-er-ayts).

You can draw a graph to show acceleration, or how speed changes with time. Put *speed* along the vertical edge, and *time* along the horizontal edge.

At the start the car is motionless. After 5 seconds it is going 10 miles an hour. After 10 seconds it is going 20 miles an hour. After 20 seconds it is going 40 miles an hour. It keeps accelerating at the same rate. How fast is it going after 15 seconds? After 35 seconds? How long does it take for the car to accelerate to 60 miles an hour?

3. What would the speed line look like on a speed-time graph if the speed were steady? Prove it.

What to Measure?

Throughout the history of science, measurements have been used to help men explain and develop their ideas. In fact, almost every scientific idea is a result of new measurements or a result of using known measurements in new ways. You will now read the stories of three important discoveries and how they were made with the help of measurements.

Lavoisier and Chemical Reactions

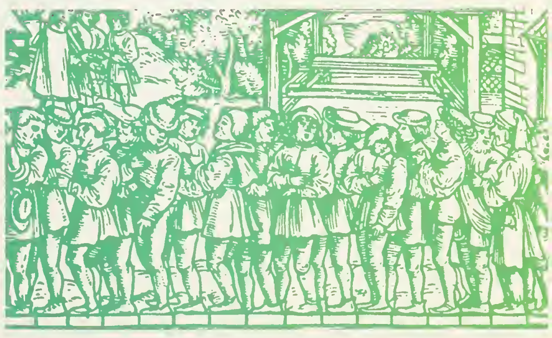
Before 1800 it was thought that when a substance burned it lost something. After wood is heated or burned, it weighs less. When cloth is heated, it loses weight. Chemists of long ago said that if a substance loses weight when it is burned, then something must be released into the air. All ideas of what happened in a chemical reaction were based on this belief.

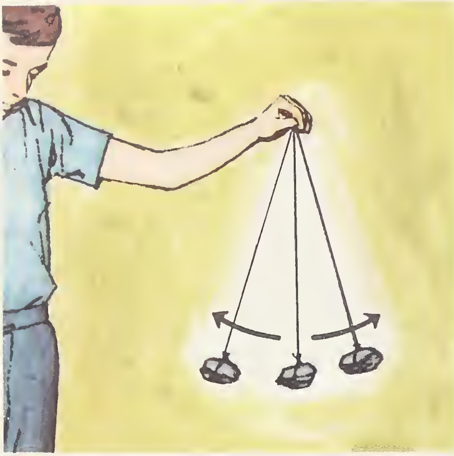
But chemists began to use more accurate balances, or scales, to measure mass, and they discovered new facts. With these new balances, scientists learned that when mercury, zinc, or copper is heated, it *gains* weight. This fact did not fit the old ideas. If a substance that remains in the same place gains weight, it must have more mass. The additional mass must somehow come *from* the air. What substance in the air is added to heated mercury, zinc, or copper?

These new measurements and observations were important to the French chemist Antoine Lavoisier (an-TWAHN lah-vwah-zee-AY). They led him to search for the substance that was removed from the air when something was burned or heated. After many experiments and very careful measurements, he found that the substance was a gas that he called oxygen. His discovery of oxygen led chemists to turn from one idea about chemical reactions to another. They now believe that when something burns it takes some oxygen from the air.

Without careful measurements and the knowledge of what the measurements meant, chemistry would not have changed as it did in the late 1700's.

This picture made in 1575 shows 16 men standing toe to heel. The length of the line was given the value of 16 feet and was then divided into 16 equal parts. Can you tell why this was done?





Galileo and the Swinging Stone

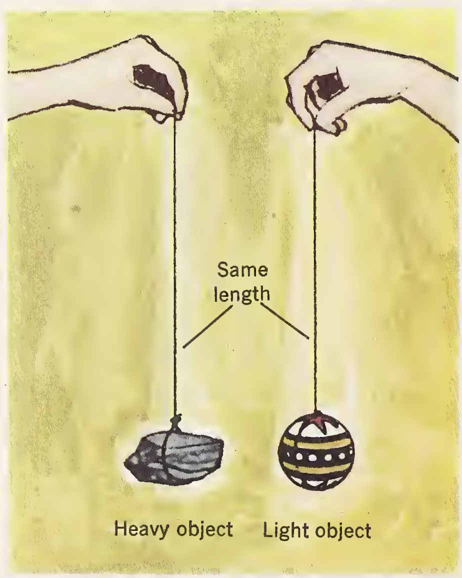
Tie a small stone, or any other small, heavy object, to the end of a string. Start it swinging as in the picture.

Scholars and teachers in ancient times studied this simple movement carefully many times. To them, the most interesting thing about this movement was that the stone finally stopped swinging. When it stopped, it hung straight down. Scholars of ancient times said that any heavy object went from a high position to a low one because it was the nature of heavy objects to do that. The ancient scientists wanted to know how long it took for the stone to hang straight down. They made measurements to find the answer.

Galileo looked at the swinging stone in an entirely different way. He wanted to know whether the time it took for heavy objects to swing from the lowest point back to the lowest point in the swing was the same as the time for light objects. He made many measurements.

He took two strings of the same length. He tied a heavy object to one string and a light object to the other. Then he started both objects swinging and measured the time for each swing. He compared his measurements. Try it yourself. What do you discover?

Galileo's experiments with the swinging stone, the pendulum, helped change man's idea of how objects move. His experiments helped to establish a new



science of motion. His experiments also showed the importance of measurement in comparing things.

Can you think of anything else about the swinging weight that might be interesting to measure?

Herschel and a New Planet

In 1781 the German-British astronomer William Herschel (HER-shul) discovered the planet Uranus. For many years, other astronomers took many measurements of Uranus' position in order to determine its orbit. The measurements showed some very unusual things about the orbit.

Astronomers thought that the gravitational force of some unknown object in the solar system was causing the peculiar orbit. In 1846 the French astronomer Urbain Leverrier (er-BAN leh-vehr-ee-AY) determined just where this object *should be*. Soon afterward a new planet, Neptune, was found in that spot. Tell about the importance of measurement in finding Neptune.

Using What You Have Learned

1. Get two balls, a light one and a heavy one. Hold the light one up high. Now figure out where the heavy one must be held so that both balls strike the ground at the same time when they are released at the same instant. Measure the difference in the heights of the two balls. Drop them. What happens? Why?

2. Roll a heavy, solid ball, like a croquet ball, down a slide. Roll a light, solid one, like a rubber ball, down the slide. Do they take the same time to reach the ground? What measurements can you make to find out?

3. Read about how Lavoisier discovered oxygen. Make a report to the class telling what materials he used and what measurements he made.

4. Read about the motion experiments of Galileo. Perhaps you can demonstrate one of his other experiments to the class.

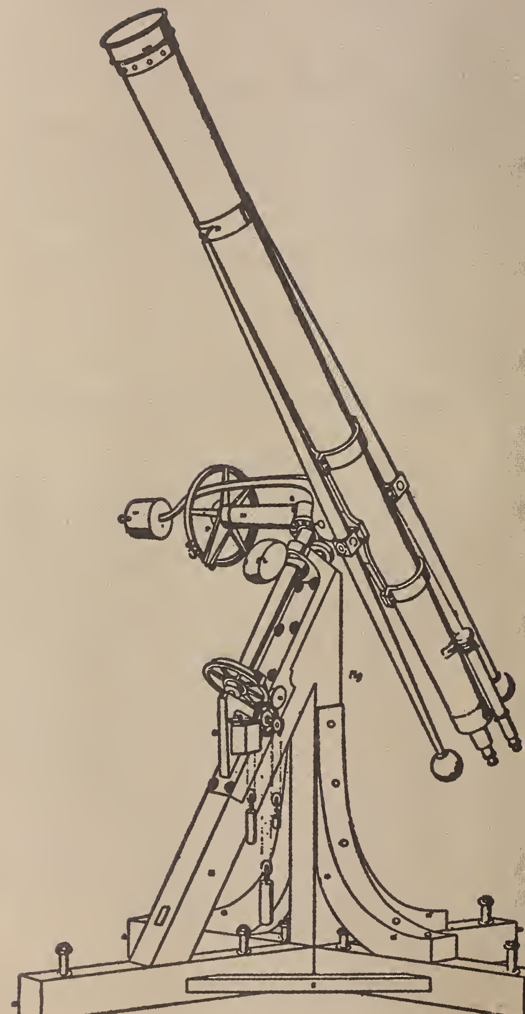
Friedrich Wilhelm Bessel

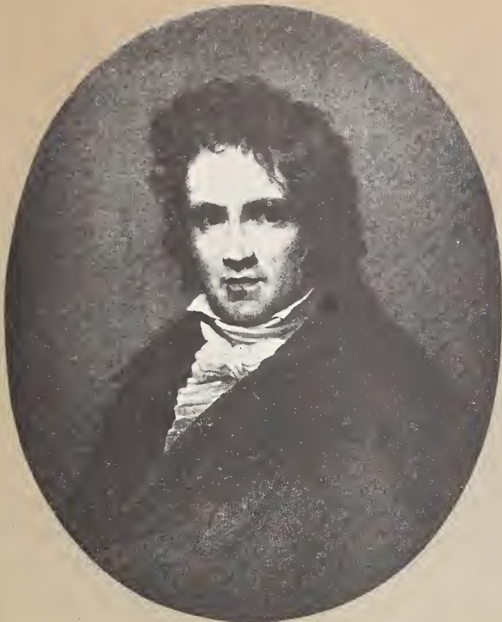
(1784–1864) Germany

For thousands of years, men looked at the stars and believed them to be much too far away for anyone to measure their distance from the earth.

To see why this was believed, do the following. Hold your finger at arm's length in front of you and line it up with an object in the far distance. Now, without moving your finger, look in the far distance with your other eye. (Use your other hand to cover one eye at a time.) Your finger will appear to jump to one side against the fixed background. If you move your hand rapidly back and forth, covering first one eye and then the other, your finger will appear to jump rapidly from side to side.

This effect is called *parallax.* The farther away an object is, the less the parallax: that is, the less it will appear to jump against its background. You can experiment with objects around you to see that this is so. It is difficult to measure the distance of far objects accurately with your eyes because your eyes are too close together. By using rangefinders, which increase the distance between your eyes artificially, the parallax is increased





and distant objects can be measured accurately.

It was because astronomers could not discover any parallax among the stars, no matter what instruments they used, that they believed the distances of the stars were too great ever to be measured. It was not until a German astronomer, Friedrich Wilhelm Bessel, discovered a way of making the closer stars appear to shift from side to side—as your finger did—that their distance could be measured.

Bessel's father had wanted him to become a businessman, and the young man had studied to be an accountant. But Bessel was much more interested in the stars, so he secretly studied astronomy in his spare time. When he was twenty years old, he figured the orbit of Halley's comet and sent the result to a famous astronomer. The astronomer was so impressed that he found Bessel a position in an observatory.

Bessel became interested in the distance of the stars. He decided the distance could be measured in the following way. As his two "eyes" he used the position of the earth in space as it revolved around the sun. Every six months, the earth has changed its position by 184 million miles as it moves in a great circle around the sun. By measuring the position of a star, called 61 Cygni (SIG-nee), very accurately among surrounding stars and then waiting six months before measuring the position of the star again, Bessel was able to show that 61 Cygni had shifted a very small amount against the background of stars. From the amount of this shift he was able to calculate that 61 Cygni was 35 *trillion* miles from the earth.

Bessel's discovery made possible the direct measurement of distances to the nearer stars.

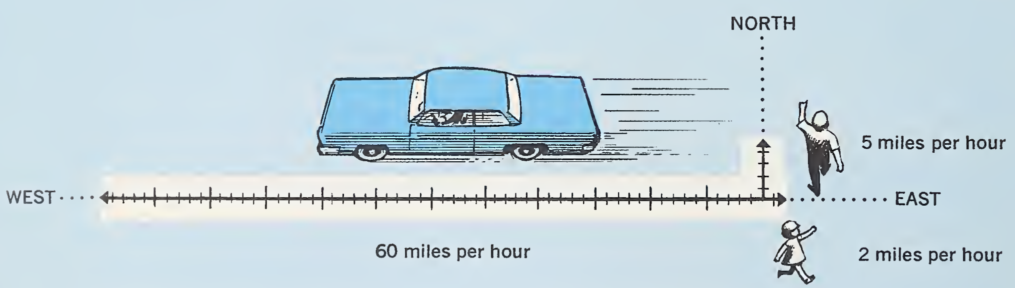
How Much Information?

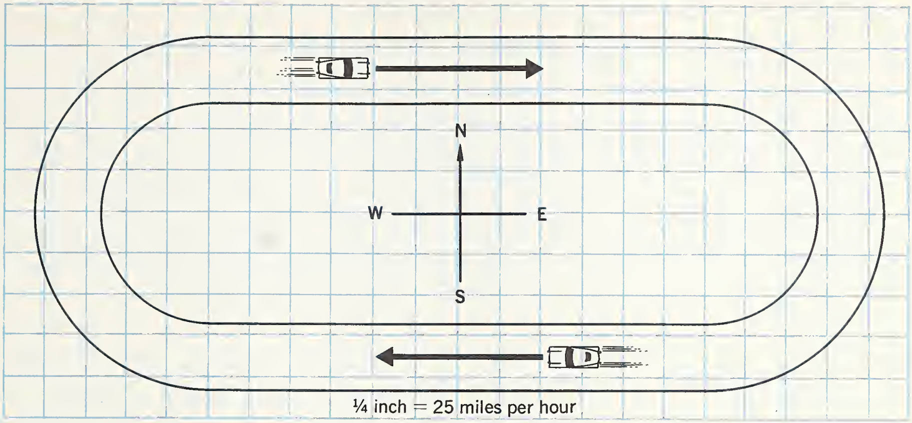
Two boys start running from the same spot. Bob runs 11 miles per hour. Tom runs 12 miles per hour. Which one will reach the telephone pole first? Tom, you say. But what if Tom decides to run the other way first? To be sure about which boy will reach the pole first, you must know which way they are running. You must know their *direction.*

Speed and Velocity

You know that the speed of an object is the distance it travels in a certain amount of time. If you walk at a speed of 4 miles per hour, in one hour you have gone 4 miles. Your younger brother or sister may walk at a speed of 2 miles per hour. Your father may drive his car on the road at 60 miles per hour. The earth moves in its orbit at the speed of about 18 miles per second.

But just as important as speed is the direction in which an object travels. How fast an object travels *in a certain direction* is called the **velocity** (vuh-LAHSS-uh-tee) of the object. If you walk 5 miles per hour north, in one hour you will be 5 miles north of the place where you started. Your younger brother or sister may walk 2 miles per hour east. Your father may drive 60 miles per hour west.





A racing-car driver whizzes around a track at a speed of 100 miles per hour. His speed stays the same at all times. But his velocity keeps changing, because as he goes around the track, he keeps changing his direction. At the top of the diagram, you see an arrow representing the driver's velocity at one instant. This arrow represents 100 miles per hour *eastward*. At the bottom of the diagram is an arrow which represents a different velocity. He is traveling at the same speed, but in the opposite direction. The arrow at the bottom represents a velocity of 100 miles per hour *westward*.

The velocity of the racing car driver, of the earth, of your father's car, or of anything is a quantity called a **vector** (VEK-ter). A vector has both size and direction. Velocity vectors are one type of vector. They tell *speed* and *direction*.

Vectors are represented by arrows. After you have determined the direction of movement, you can draw a velocity vector by drawing a line and putting an arrow tip on one end of it to show its direction. After you measure the speed of movement, you make a scale in much the same way a mapmaker does. You may decide that one-quarter inch on the line represents 5 miles per hour. It could represent 1,000 miles per hour or any other speed you choose. For the vectors drawn in the racing car diagram, one-quarter inch represents 25 miles per hour. The point of the arrow indicates the direction of the car.

Draw vectors to show the speed and direction of each man below. Let one inch equal 4 miles per hour.

1. A man walking at 1 mile per hour eastward.
2. A man walking at 4 miles per hour eastward.
3. A man running at 9 miles per hour eastward.
4. A man running at 9 miles per hour westward.

Now draw these vectors. Make up your own scale.

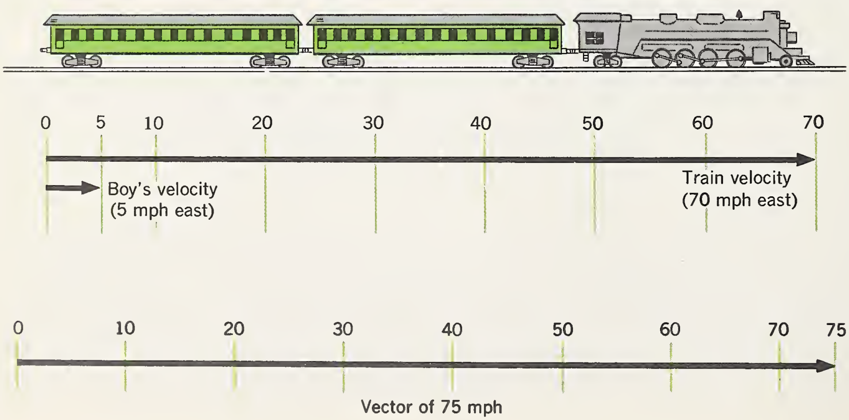
1. A snail moving 1 foot per minute northward.
2. A pencil rolling 5 feet per minute southward.
3. Smoke drifting 20 feet per minute eastward.

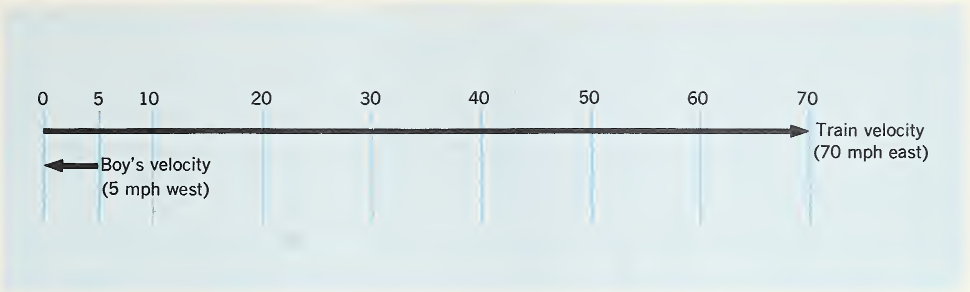
Combining Vectors

In the picture below you see a train traveling eastward at 70 miles per hour. Beneath the train you see a vector representing its velocity. A boy on the train gets up and walks quickly toward the front at 5 miles per hour. You see the vector representing his velocity. Is he going faster than the train?

It does not seem so to the other passengers. To them, the boy seems to be moving at 5 miles per hour. But what about his velocity as seen by an observer standing still on the ground? To the observer, the boy seems to be moving even faster than the train. Actually, his velocity in relation to the ground is 75 miles per hour eastward.

Notice how the vectors are drawn. Both point the same way. What does this tell you about the direction of the train and the boy?



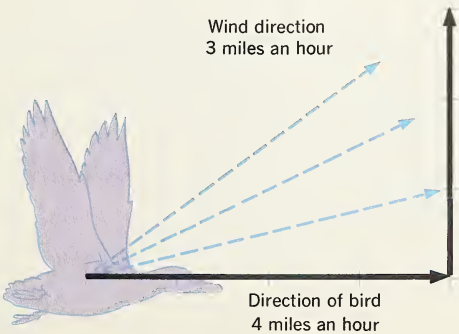


Now the boy hurries back to his seat at the same speed, 5 miles per hour. His velocity is 5 miles per hour westward. What is his velocity seen by the observer standing still on the ground?

Again you can combine the vectors. But notice that they are in opposite directions, so the resulting vector is 65 miles per hour eastward. You have to subtract the boy's speed from the train's speed to get his velocity as seen by someone watching the train pass.

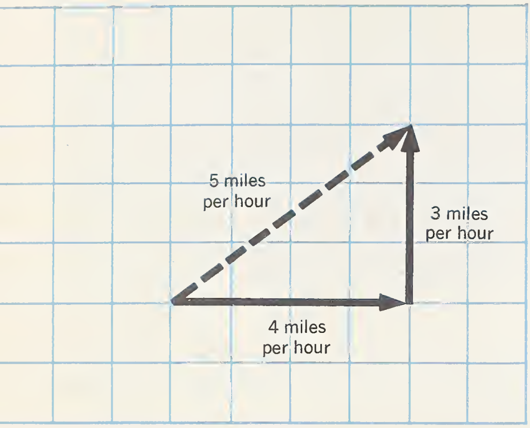
Another Kind of Vector Problem

Here is another type of vector problem. A bird flies 4 miles per hour *eastward*. The wind blows 3 miles per hour *northward*. What is the bird's velocity as seen by an observer standing still on the ground?



Notice how this problem differs from that of the boy on the train. The boy was walking in one direction and the train was moving in the opposite direction. In this problem the wind is blowing at right angles, like this: ∟ or ┐ or ┌ or ┘, to the flight of the bird. The bird flies straight eastward, but it flies in a stream of air that is moving in a northward direction. The heavy line shows the bird's aim, and the dotted lines show how the wind changes the bird's course.

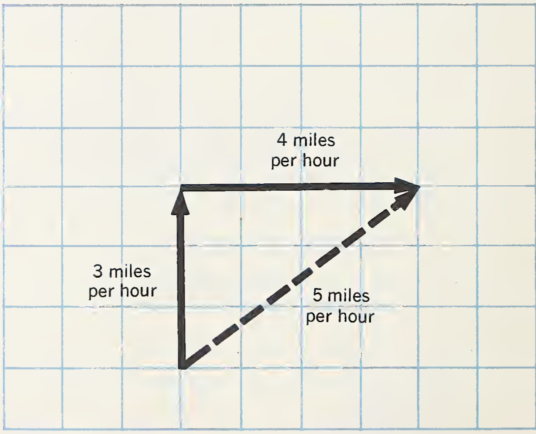
It is easy to see that the wind is changing the bird's direction. Does it also change the bird's speed? Will a bird flying at 4 miles per hour in relation to the ground go faster, slower, or at the same speed when a 3-mile-per-hour wind blows at it from a right angle?



You can use vectors to solve this kind of problem, too. A vector is drawn representing the velocity of the bird. In the diagram, one-quarter inch stands for 1 mile per hour, so we need four times that length, or one inch, to stand for 4 miles per hour. The arrow tip shows that the direction is eastward. From the arrow tip of this vector another vector is drawn. It stands for the velocity of the wind, which is 3 miles per hour northward. Notice that a line three quarters of an inch long is needed to show this. The tail of the first vector and the tip of the other are connected by a dotted line. An arrow is drawn on it because it, too, is a vector. This new vector represents the velocity of the bird as seen from the ground. Notice that it is in a northeasterly direction. Measure the vector. Can you tell how fast the bird is going?

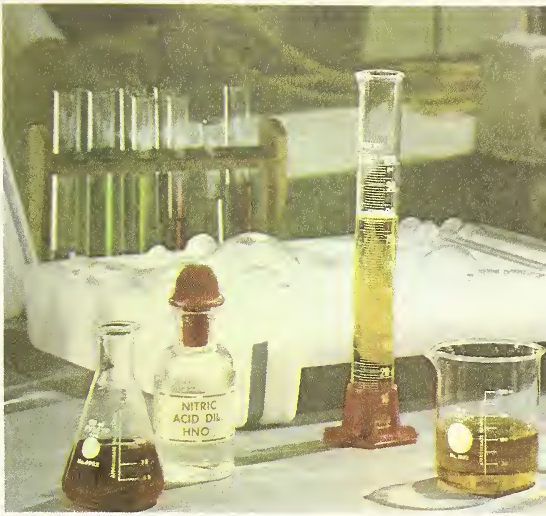
It does not matter which vector you start with. Just put the tail of the second vector at the tip of the first vector. In the drawing below, the wind vector is drawn first. The answer is the same.

Vectors are used to represent any quantity that has direction. The force exerted by you on your chair is a vector quantity. The force is the pull of gravity downward on your mass. Magnetic force, electrical force, and all other forces are vector quantities. By using vector diagrams like those in this unit, scientists can find the result when several forces act on an object, just as you found the velocity of a bird flying on a windy day.



The Scientist and Measurement

In this unit you have learned the importance of making exact measurements and using standard units. You have seen how we use measurements to help us solve many different kinds of problems. You have learned how we use formulas, graphs, and vectors to help us see relationships quickly and clearly. Measurements also help the scientist to understand the world around him better. They help him to explain things that earlier scientists could not understand. Measurements also show that things are not always what they appear to be. Tell about times in your life measurements have shown things to be different from the way they appear to be.



In the picture, you see some of the tools of the chemist. Notice that the beakers, flasks, and cylinders all have units of measurement printed on them. Why are measuring instruments vital to the work of the chemist?

Using What You Have Learned

1. A bird is flying 15 miles an hour northward. The wind is blowing 5 miles an hour northward. What is the velocity (speed and direction) of the bird as seen by an observer standing still on the ground?

2. Another bird flies 15 miles an hour southward, while the wind is blowing 5 miles an hour northward. What is the bird's velocity as seen by an observer on the ground?

3. Another bird flies 15 miles an hour northward. The wind blows 15 miles an hour southward. What is the bird's velocity as seen by an observer on the ground?

WHAT YOU KNOW ABOUT

The Scientist's Way

What You Have Learned

Measurements help the scientist to understand the world around him. Measuring things exactly is often part of a scientist's work.

Standard units of measurement are those that everyone agrees to use. The foot and the pound are standard units in the **English system** of measurement. The meter and the gram are standard units in the **metric system.** Most units of measurement are not natural units; only the day and the year come close to being natural units.

Mass is the amount of **matter** in an object. **Volume** is the amount of space an object occupies. The mass of an object never changes, but the volume and weight of an object change according to its temperature and its distance from the center of the earth.

A **formula** is a statement of a relationship among units of measurement. A graph is a picture of such a relationship.

A **vector** quantity has both size and direction. **Velocity** is a vector quantity, for it is a measurement of both the speed and the direction of a moving object.

Checklist of Science Words

Here are some science words you read about in this unit. Can you tell what you have learned about each one?

accelerate	mass	standard units	velocity
formula	sea level	vector	volume

Complete the Sentence

Write the numbers 1 to 5 in your notebook. Next to each number write the answer that best completes the sentence.

1. The amount of space a substance occupies is its ___?___.
2. The level of the surface of the sea is the ___?___ ___?___.
3. The amount of matter in an object is its ___?___.
4. The pull toward the center of the earth is called ___?___.
5. How fast an object travels in a certain direction is its ___?___.

Comparing Metric with English Units

Which unit in the metric system is closest to each of the following units:

1. mile?
2. inch?
3. pound?
4. yard?

Can You Tell?

1. What are the differences between natural units and standard units? Give examples of natural units and standard units.
2. How does the English system differ from the metric system?
3. What is the unit of mass in the metric system? What is it in the English system?
4. How does the Fahrenheit scale for measuring temperature differ from the Centigrade (Celsius) scale?
5. How would you go about finding the weight of a heavy object such as a boulder without using scales to weigh it?
6. Why do scientists prefer the metric system to the English system of measurement?

YOU CAN LEARN MORE ABOUT

The Scientist's Way

What Are the Words?

Write the words in your notebook.

1. The system in which the inch, the foot, and the mile are standard units.
2. The substance of which all objects are made.
3. The attraction between two objects.
4. The instrument on a submarine that uses sound to measure distance.
5. To increase in speed.
6. A quantity, represented by an arrow, that has both size and direction.
7. The amount of space something occupies.
8. The system in which the centimeter and the meter are standard units.
9. How fast an object travels in a certain direction.
10. The amount of matter in an object.

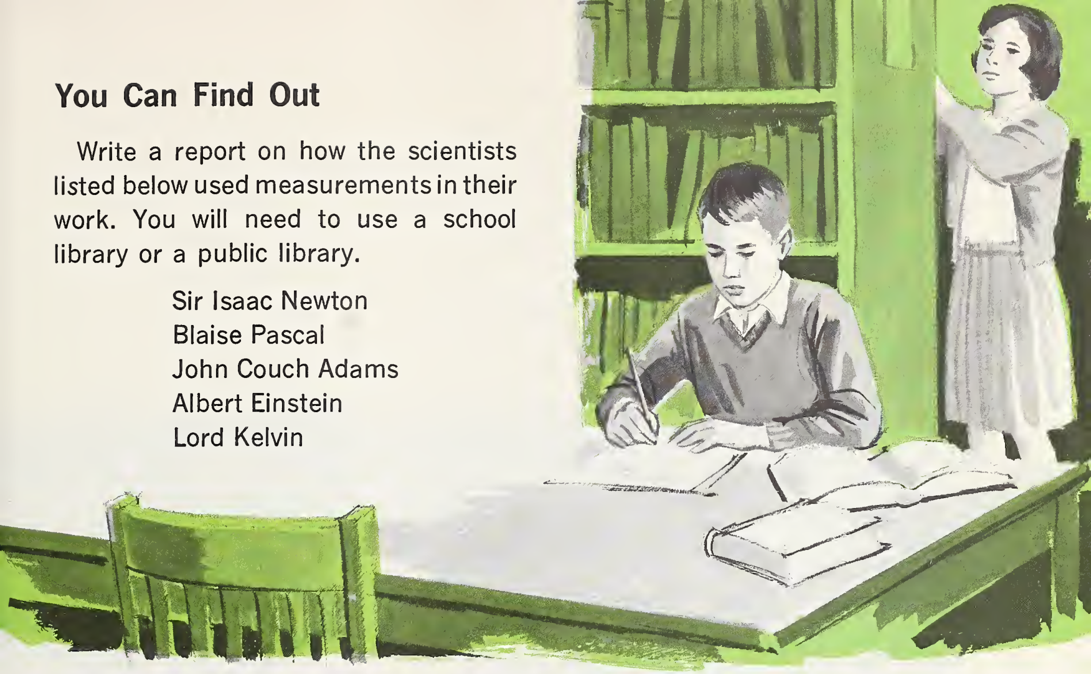
You Can Make a Time Line

A time line is a series of pictures that shows how something developed. Make a time line to show how our system of measurement has developed from earliest times to today. For ideas, read the books listed under **You Can Read.**

You Can Find Out

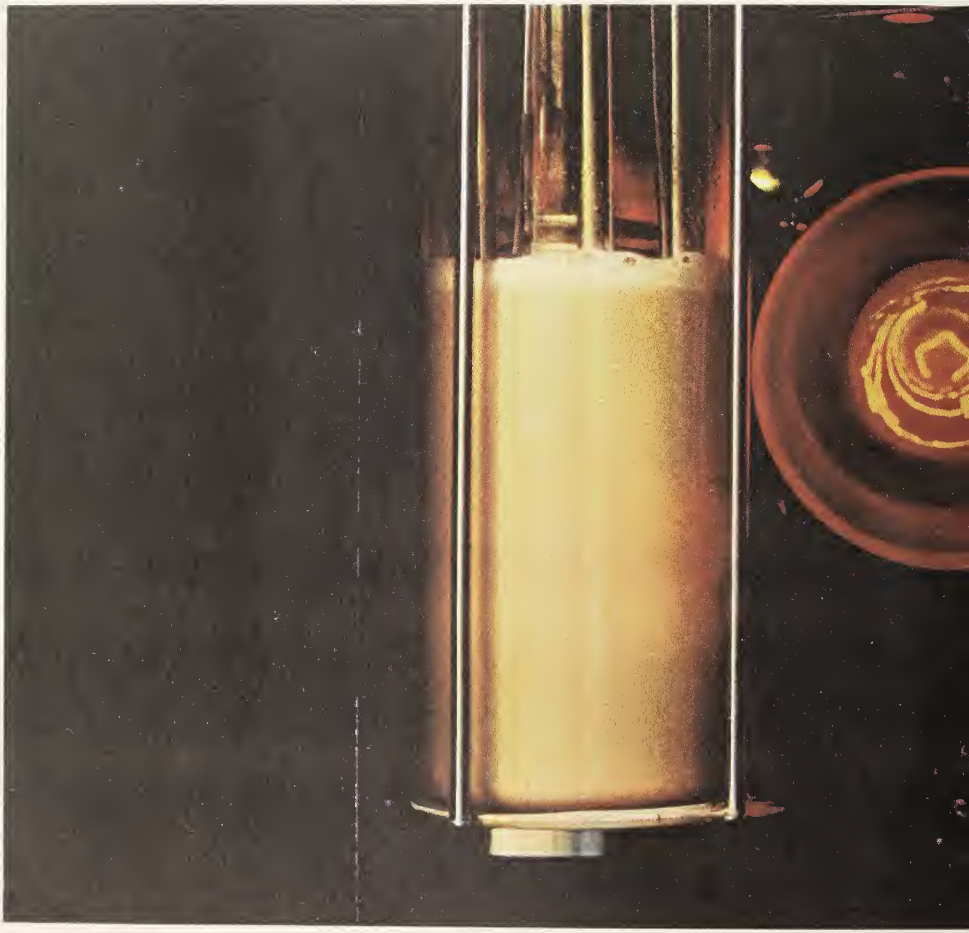
Write a report on how the scientists listed below used measurements in their work. You will need to use a school library or a public library.

Sir Isaac Newton
Blaise Pascal
John Couch Adams
Albert Einstein
Lord Kelvin



You Can Read

1. *Things That Measure,* by Philip B. Carona. A history of measuring instruments together with simple home experiments.
2. *Mathematics: The Language of Science,* by George O. Smith. Traces the development of mathematics and discusses Galileo, Newton, and others.
3. *Take a Number,* by Jeanne Bendick and Marcia O. Levin. Numbers—from finger counting to computers—are explained.
4. *New Ways in Math,* by Arthur Jonas. The story of mathematics from the days of bartering to the space age.

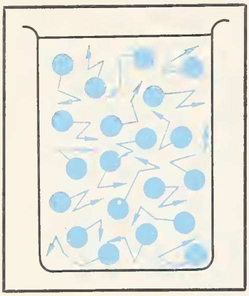


2

Heat and Molecules

Molecules and Matter

How Do Objects Become Heated?



Look at the objects shown on page 36. They all look different. Yet they are also alike. Scientists use the word *matter* when they talk about what all objects are made of. Rocks, water, air, and you are matter. Matter is made up of molecules. Rocks, water, air, and you are made of molecules.

Molecules and Matter

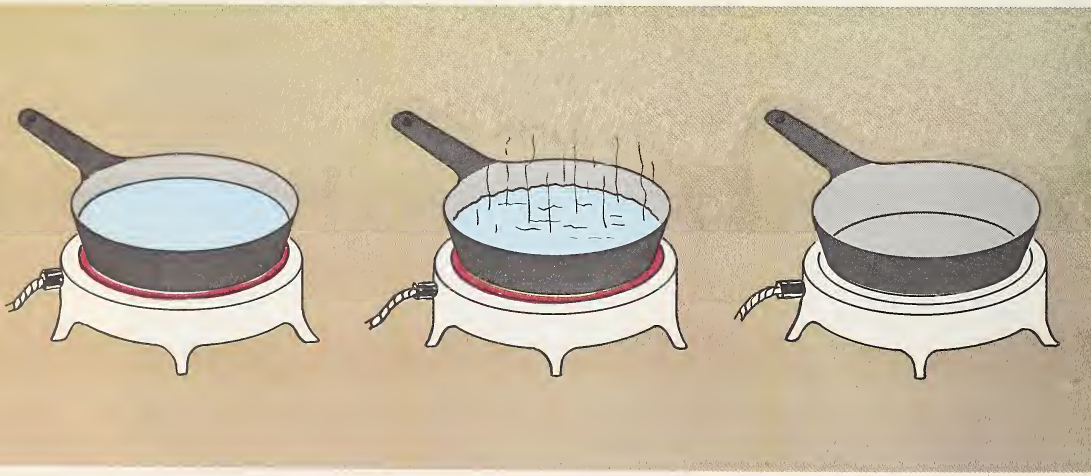
There are five important ideas that will help you to understand the new ideas in this unit.

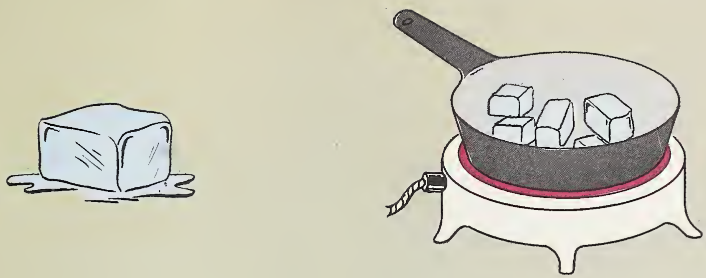
1. Matter may be in one of three states: solid, liquid, or gas. Can you give some examples?

2. A substance such as water can be changed from a solid to a liquid and then to a gas by heating it.

3. Some substances, such as sugar, dissolve in water. When sugar is dissolved in water you can no longer see the sugar. You know it is there because the water tastes sweet. Matter may change its form, but it cannot disappear completely. Sugar added to water increases the amount of matter in the glass, whether or not you can see this happening.

Name the three forms of matter shown in the three pans below.





How is the ice changed from a solid to a liquid and then to a gas?

You also know that when heat is added to water, substances such as bouillon cubes will mix with the hot water faster than they will with cold water.

4. An atom is the smallest particle of an element. For example, the smallest particle of copper is an atom of copper.

5. A molecule is the smallest particle of a substance that has all the characteristics of the substance. A molecule of water is the smallest particle of water that can exist and still be water. A molecule of water contains two hydrogen atoms and one oxygen atom. If a water molecule is broken up into smaller particles, the particles are atoms of hydrogen and oxygen.

How did scientists find out about molecules if molecules cannot be seen? They found out in very much the same way that you might. For example, you enter a room. You find a toy block, a small shoe, cookie crumbs, or crayon markings on a piece of paper. You say, "My little brother has been here." You did not see or hear your brother, but from the evidence around you, you get the idea that he has been there. The little-brother idea seems to be a good one to explain why things are topsy-turvy.

This is something like the way that scientists formed their ideas about molecules. They developed the idea in order to explain many things that they observed with their senses.

Evidence of Molecules from the Sense of Smell

Has your mother ever left a bottle of perfume open? Perhaps your father has left a can of paint open. Or maybe your mother makes roast beef for supper. You can smell all these things from a good distance away. The smells of perfume, roast beef, and fresh paint are all one kind of evidence that supports the idea of invisible molecules. Can you tell how?

OBSERVATION

Does the Sense of Smell Give Evidence of Molecules?

What You Will Need

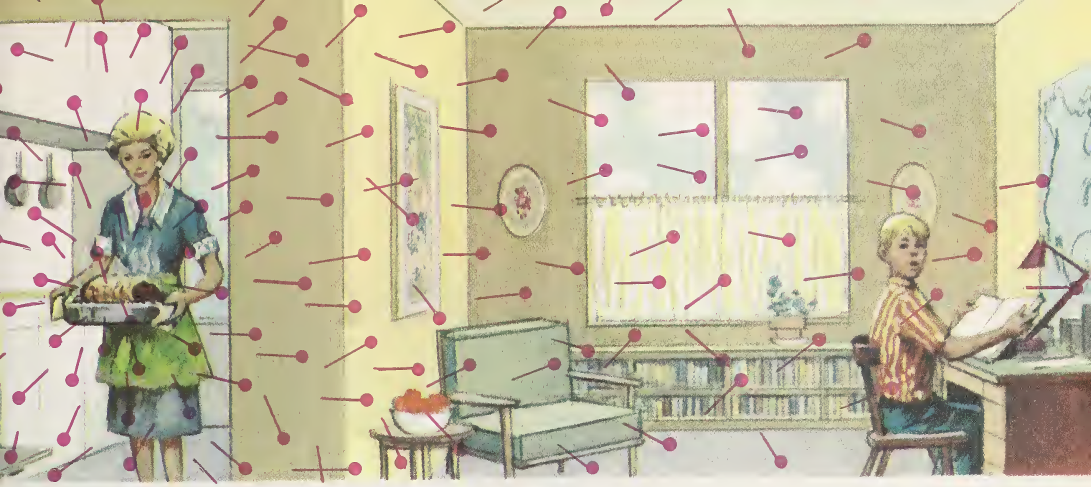
onion knife

How You Can Find Out

1. As the entire class faces the front of the room, have someone go to the rear of the room and cut the onion in half.
2. Have members of the class raise their hands when they smell the onion.

Questions to Think About

1. Did the people nearest the onion or farthest from it smell it first?
2. Did they see anything move from the onion to their noses? How, then, could they smell it?
3. How could you explain what happened?
4. Invisible molecules must have moved from the object to their noses. How?
5. You might want to try some other objects to see if your sense of smell gives evidence of molecules. Try using perfume, glue, paint, household cleanser, and baby powder. Try timing how long it takes the class to react to each. How do you account for the differences in reaction time?



Molecules from the onion that produce the odor escape into the air. But why did they escape? Molecules are in constant motion. They move in all directions and constantly bounce into each other. Therefore, when the onion was cut, some of the bouncing molecules escaped into the air. Since the molecules of the gases that make up the air are also constantly in motion, they helped to bounce the other molecules along from the onion to the members of the class.

You can observe what happens when the bouncing molecules of water hit small objects. Mix a tablespoonful of homogenized milk in one-half cup of water. Put a drop of the mixture on a microscope slide. Place a cover slip over the drop and examine under a microscope. You will see small bits of milk fat distributed throughout the water. As you observe these bits of fat, you will notice that they appear to be shaking. They shake, or vibrate, because they are being bombarded by invisible water molecules.

The movement of molecules from a source such as the onion throughout the air in a room is caused by currents of air carrying the molecules.

Molecules of one kind of matter also move from an area where there are many such molecules to an area where there are fewer such molecules. There are more molecules in the onion particles closer to the onion. These molecules move slowly out into an area where there are not so many. This process is called **diffusion.** Now can you explain why you can smell paint and roast beef from a distance?

Evidence of Molecules from the Sense of Sight

Do molecules also spread out in liquids? If so, can you see it happen?

After you do the activity to find out if your sense of sight gives evidence of molecules, try to think of other ways to show that molecules move.

OBSERVATION

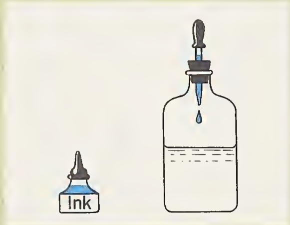
Does the Sense of Sight Give Evidence of Molecules?

What You Will Need

ink
water
glass bottle with one-holed rubber stopper
medicine dropper

How You Can Find Out

1. Put water in the glass bottle.
2. Place the one-holed rubber stopper in the bottle.
3. Put some ink in a medicine dropper.
4. Place the dropper in the hole of the stopper. Squeeze one drop of ink into the water.



Questions to Think About

1. What do you see? Why?
2. Did you hypothesize that ink is heavier than water and that is why it is pulled down?
3. Turn the bottle sideways. Does the action continue?

You can see that it is not only gravity that forces the molecules to the bottom. Something else is happening. No matter which way you turn the bottle, you will see the water in the entire bottle slowly turn blue.

Particles of ink are being carried through the water by the movement of water molecules. The particles of ink diffuse through the water. They move from an area where there are many such particles to an area where there are fewer.

Try the same activity with a gallon jar of water and one drop of ink. Can you see the ink? You know the ink particles are there. You see their outward movement, but the particles become so far apart that they do not change the color of the water.

More Evidence of Moving Molecules

The activities you have done show evidence that molecules not only exist but also move. There are other ways of gathering evidence for molecules.

Have you ever seen substances disappear? Put one teaspoonful of salt in a glass of water. Stir. Can you still see the salt? Now taste the solution. How does it taste? Boil the solution until all the water evaporates. What do you see in the pan when all the water is gone?

When you stirred the salt in the water, the crystals of salt separated into particles that you could not see. In fact, even with the most powerful microscope, scientists cannot see particles of salt dissolved in water. When you tasted the solution, you proved that the salt molecules were still there. How? When you boiled the solution until all the water evaporated, you noticed that the particles of salt formed crystals again. What caused the crystals to break up when they were put into water?

Using the many kinds of evidence that you have just read about, scientists have come to believe that molecules exist and move about.

How Do Molecules Behave in Solids, Liquids, and Gases?

All solids have one thing in common that is different from liquids and gases. They tend to keep their shape.

A model will help you understand how molecules behave in solids and why solids keep their shape. Imagine some marbles packed in a box so that the entire bottom is covered. If you tilt or wobble the box a little, the marbles move, but they do not move past one another. Their arrangement in the box is fixed, or locked.

A liquid such as water does not have a fixed shape, as solids do. A liquid takes the shape of the container in which it is put. The arrangement of the molecules in a liquid is not fixed or locked. It is *fluid*. The molecules are always slipping and sliding past each other.

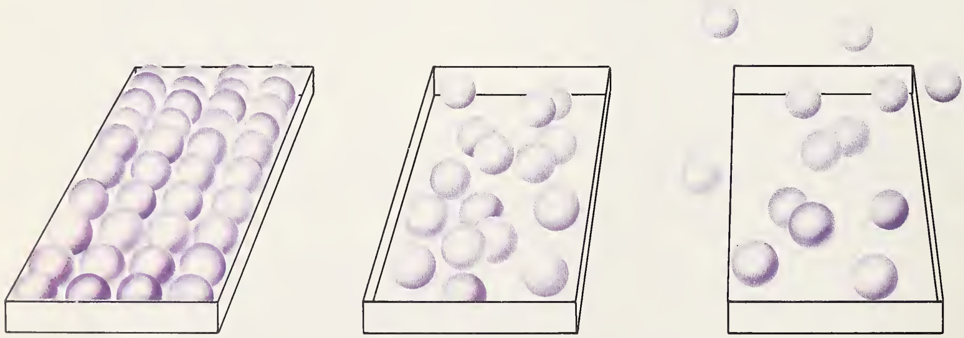
The molecules in a gas have no fixed position. They are constantly in motion with no particular pattern. They bounce off each other in all directions.

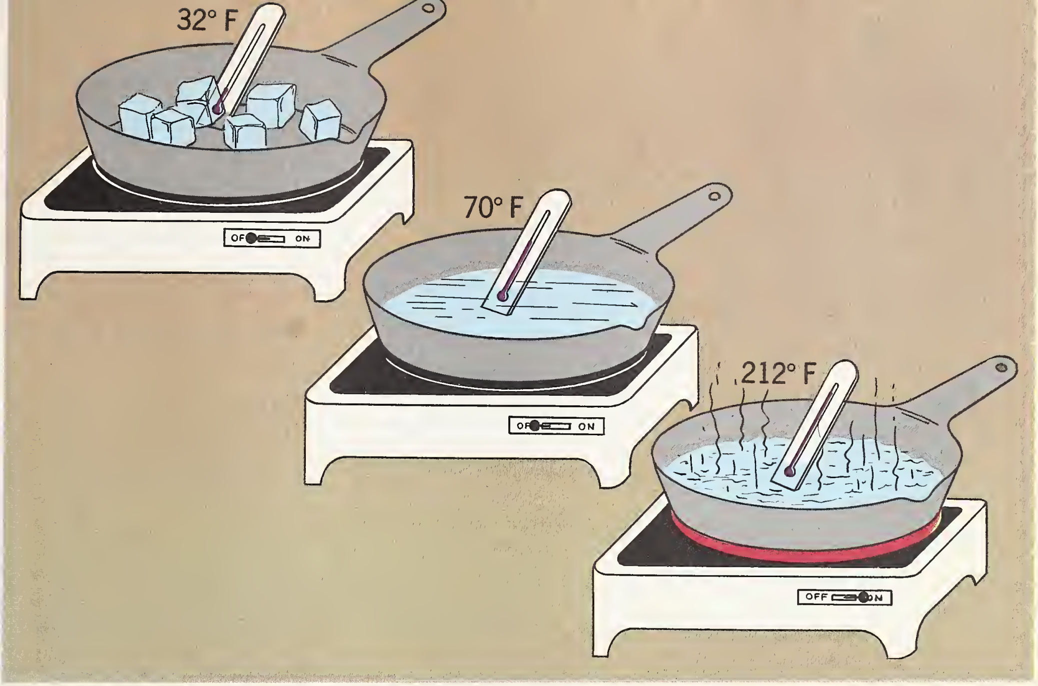
The molecules in a gas move more rapidly than do the molecules in a solid. They also move farther apart from each other.

When the position of molecules is fixed, the particles move about less. More of them can fit into a certain amount of space. For example, a box would hold fewer particles of matter existing as a gas than of the same matter existing as a solid.

The arrangement of molecules determines whether matter is a solid, liquid, or gas.

Can you tell which model shows a liquid, which a solid, and which a gas?





How are the molecules of water behaving in each pan?

Why Do Molecules Behave Differently in Various States?

Look at the picture above.

How can the idea of moving molecules be used to explain what happened? What did heat do to the water?

As heat was added to the water in each situation, what happened to the molecules? The molecules became more active. They moved more rapidly and farther apart from each other. Finally, they moved so rapidly and so far apart that they all left the pan. When heat was added, water changed from a solid to a liquid and then to a gas.

Scientists now believe that the heat of an object is produced by the motion of its molecules. The faster molecules in an object move, the hotter it is. An object loses heat when its molecules move more slowly. Since molecules in all objects have motion, *all* objects have some heat—even a cube of ice.

Scientists also believe that heating things brings disorder. The molecules move about more and more rapidly and bump into each other more frequently. Cooling things, on the other hand, brings order. The molecules become more fixed in their positions.

Benjamin Thompson (Count Rumford)

(1753–1814) United States

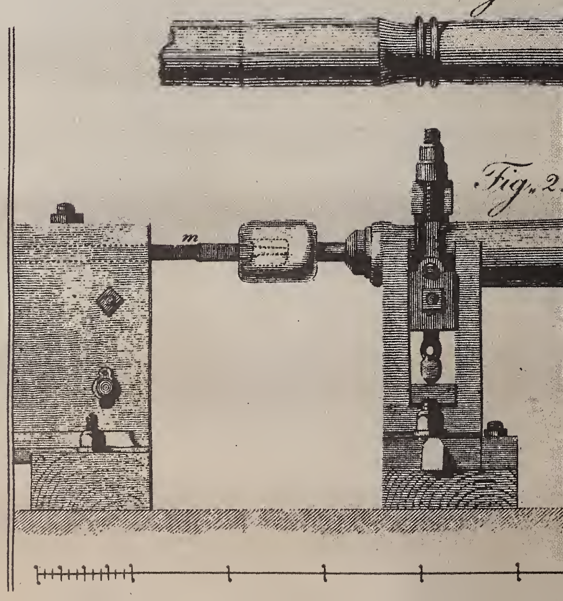
As a young man, Benjamin Thompson tried his hand at many things, including being a medical doctor, a businessman, and a schoolteacher. During the Revolutionary War, he became a spy for the British. During this time, he invented a secret ink so that he could communicate with the blockaded British Army. Arrested for spying, Thompson fled to London. After several years, he went to Bavaria and entered the service of a foreign prince. In Bavaria he gained much power and soon was given the rank of Count. He chose the title of Rumford, the ancient name of Concord, New Hampshire, in honor of the town from which he barely escaped with his life.

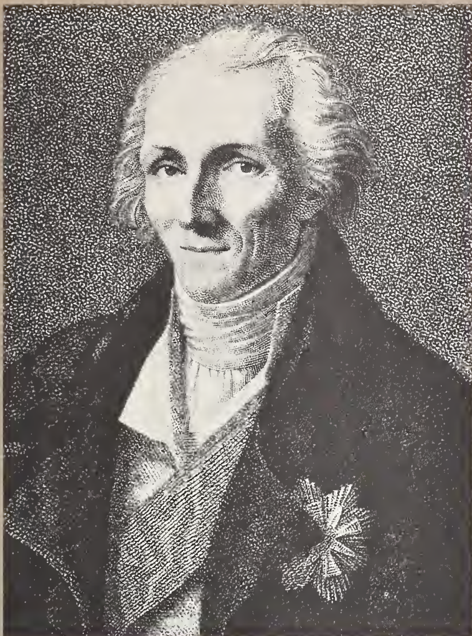
Count Rumford (as he is now known) was always very much interested in scientific problems. One problem with which he was concerned was heat. At that time scientists believed that something flowed into objects to make them hot and flowed out of objects to make them cold. They called this something *caloric.* Perhaps you have noticed that when you rub your hands together, they become warm. The scientists of Count Rumford's day said that the hands became warm because caloric flowed into them from the surrounding air.

Does heat really consist of caloric? Count Rumford knew that if caloric were a real substance, as scientists said it was, then it would weigh something. He carefully experimented and found that all objects weighed exactly the same when they were hot as they did when they were

Fig. 1.

Fig. 2.



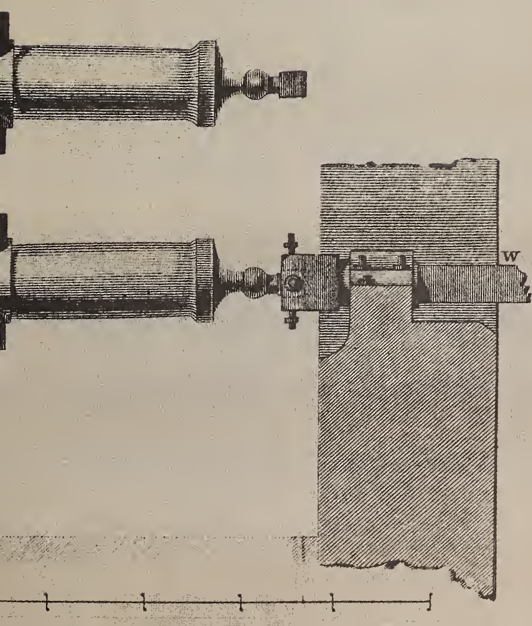


cold. He reasoned then that caloric was not a substance, since it had no weight.

Next Count Rumford noticed that when a brass cannon was being bored in the arsenal, much heat was given off. He conducted more experiments and discovered that *friction,* or rubbing, between the boring tool and the brass of the cannon made the heat. The mechanical energy used to bore the hole was changed into heat energy. Caloric did not make things hot or cold. In fact, caloric did not even exist.

Although Count Rumford discovered that rubbing any two objects together made them hot, he never found out why this was so. Today, scientists know that all objects are made of molecules that are in constant motion, vibrating back and forth. The faster the molecules move, the hotter the object becomes.

Count Rumford was a pathfinder not only because of his scientific discoveries but also because he believed that basic research in a problem provides the groundwork for scientific development.



Using What You Have Learned

1. When a substance changes from a solid to a liquid, is heat being added or taken away?

2. When a substance changes from a liquid to a gas, is heat being added or taken away?

3. When a substance changes from a liquid to a solid, is heat being added or taken away?

4. When a substance changes from a gas to a liquid, is heat being added or taken away?

5. Put some *salol,* a white crystalline solid, in a test tube. If it has been in your room, what temperature will it be? Heat it briefly. It will turn into a liquid. Then remove it from the heat. In a while you will see salol form into crystals again. Explain what happened in terms of the behavior of molecules.

6. Try to get some *Wood's metal* at a hardware store. Put it in a pan of water and heat it. Take the temperature of the water every two minutes. Observe what happens.

Wood's metal does not need much heat to change from a solid to a liquid. Can you explain why it is often used as a plug in fire sprinkling systems?

7. Put two teaspoonfuls of salol in a jar and leave the jar in your room for several hours. Then do the following:

a. Heat some water to 100° F.

b. Place the jar with the salol in the water.

c. Put a thermometer in the water and continue to heat it.

d. Observe what happens to the salol when the water temperature is about 103° F.

e. Remove the water with the jar of salol from the heat. Does the temperature go up or down?

f. What happens to the salol as the temperature changes?

How Do Objects Become Heated?

If enough heat is added, any solid will change into a liquid and then into a gas. The temperature of matter will rise whenever heat energy is added to its particles. Sometimes it takes a large amount of heat. For example, solid iron melts to liquid form at 1535° C. At what temperature does gold melt?

There are different ways in which energy can be added to the particles in matter to make its temperature rise. You can discover these different ways yourself.

Conduction

Place a silver spoon in a jar of hot water. Keep your hand at the top of the spoon. What happens? How did the heat reach the top of the spoon? How long did it take?

The molecules in hot water are very active. They bounce around rapidly and move farther apart from each other. They have more energy than the molecules in cool water. Some of them bump against the tip of the spoon. The molecules in the tip of the spoon begin

to move faster. Some of them bump into molecules in a cooler part of the spoon, adding energy to them. They begin to move faster and farther apart from each other, bumping still others, until the molecules of the whole spoon are moving faster than they were before the spoon was put into the hot water. The spoon becomes hot. Heat has been **conducted** from one end of the spoon to the other. **Conduction** always occurs when objects of two different temperatures touch each other.

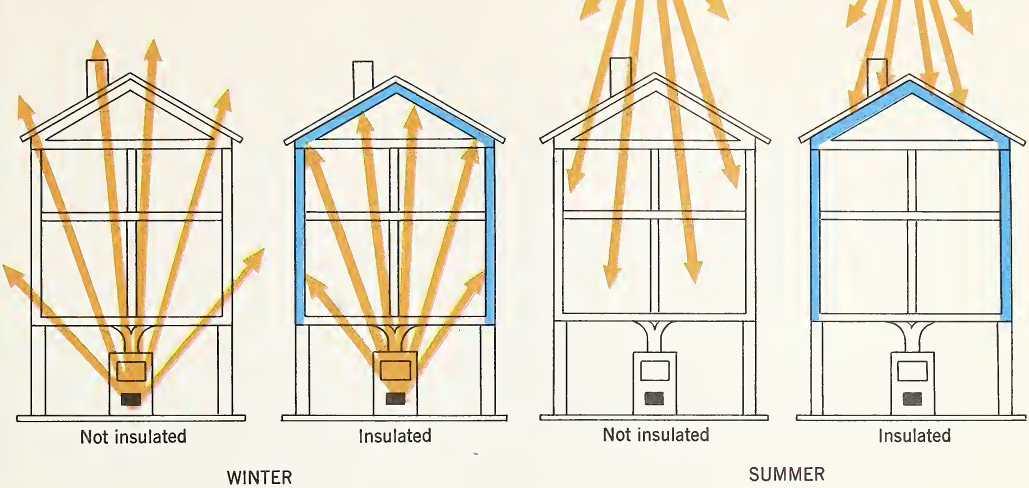
Do all kinds of matter conduct heat equally well? Try different substances in hot water—a stainless steel spoon, a piece of wood, etc. Do they all become hot at the same rate? How can you explain the differences?

Radiation

Objects get warm in another way. The sun warms you even though it is 93 million miles away. The sun is very hot. Rays from the hot sun travel to the earth. When they hit your hand they add heat energy to the molecules in your hand. The molecules in your hand move faster and farther apart from each other, bumping others. Heat is produced, and you feel warmth.

The transfer of energy by rays from the molecules of a warm object to those of a cooler one is called **radiation** (ray-dee-AY-shun). The sun is not the only object that gives off rays. All warm objects give off rays. Can you think of some ways that radiation is used in your home?

Can you explain how the children and objects in the picture below become heated?



Use what you know about heat and molecules to explain what happens to the houses in the summer and in the winter. How does insulation save money?

Can you explain what is happening in the illustrations above? Use what you know about heat and molecules.

Do you know two reasons that explain your feeling cool in a chilly room?

Expansion and Contraction

You remember that molecules move faster or slower with the addition or removal of heat. However, they do not always speed up or slow down enough to change the state of matter. For example, there may not be enough heat to change a liquid into a gas. What happens to substances when small amounts of heat are added or taken away? Let us first see what happens to solids.

From many experiments with a wide variety of solids, scientists have found that a body becomes heated when its molecules get more energy and move about more. Even in a solid, where their arrangement is fixed so that they cannot pass each other, they are more active.

Can you tell how the principle of radiation is applied to cooking meat in a broiler?

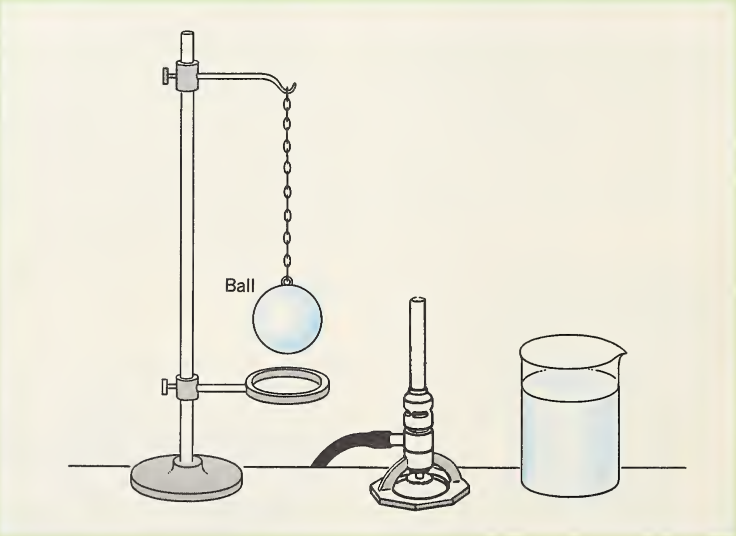
Do Solids Expand or Contract When Heated?

What You Will Need

metal ring large enough for the ball to fit through	ringstand	Bunsen burner
	ball	beaker of cold water

How You Can Find Out

1. Put the ball through the ring with both at room temperature.
2. Your teacher will heat the ring in the Bunsen burner flame for about five minutes.
3. Place the ball in the ring as you did before.
4. Put the ring into the beaker of cold water and try to place the ball through the ring again.



Questions to Think About

1. Can you explain what happened when the heated ring and the ball were fitted together?
2. What effect did the beaker of cold water have on the ring?

Your mother may use what you just learned when she opens a container with a metal cap. If it is difficult to turn the cap, she may hold it under running hot water. When heat is added to the cap, the particles in the cap move about more rapidly and take up more room than before the heat was added. Because the cap expands more than the glass, it is then big enough to be removed easily.

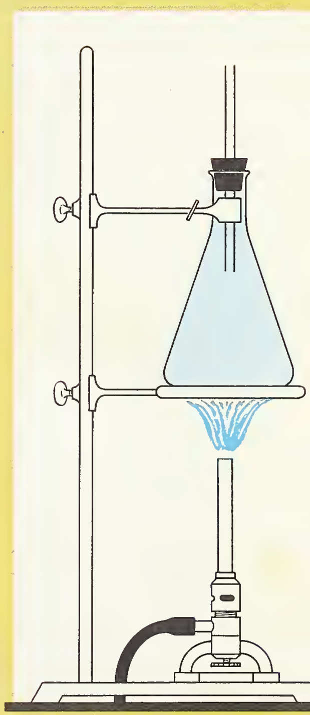
How does a liquid behave when it is heated? Again we use the scientist's way to find out.

EXPERIMENT

Do Liquids Expand or Contract When Heated?

What You Will Need

ink
8-inch glass tubing
ringstand
one-holed rubber stopper
flask
a burner



How You Can Find Out

1. Fill the flask with cold water.
2. Put a few drops of ink into it and stir. This will enable you to see the water better.
3. Put the one-holed rubber stopper with the 8-inch glass tubing through it into the flask. Be sure that the flask is full when the stopper and tubing are inserted.
4. Heat the flask gently.

Questions to Think About

1. What happens when the flask is heated?
2. How can you explain what happens when the flask is heated?
3. After you remove the heat, notice what happens.
4. Do the molecules take up more or less room as the liquid cools? How can you tell?

Heat adds energy to the molecules in a liquid. The molecules bounce against each other faster and harder and take up more room. The liquid expands.

Can you now explain the contraction of liquids when they are cooled?

The molecules of a gas are constantly in motion and are not fixed in a pattern.

EXPERIMENT

What Happens If Heat Is Added to the Molecules of a Gas?

What You Will Need

flask	one-holed rubber stopper	8-inch glass tubing
eyedropper		

How You Can Find Out

1. Insert the stopper and tube into the empty flask.
2. Use an eyedropper to put water into the tube.

Questions to Think About

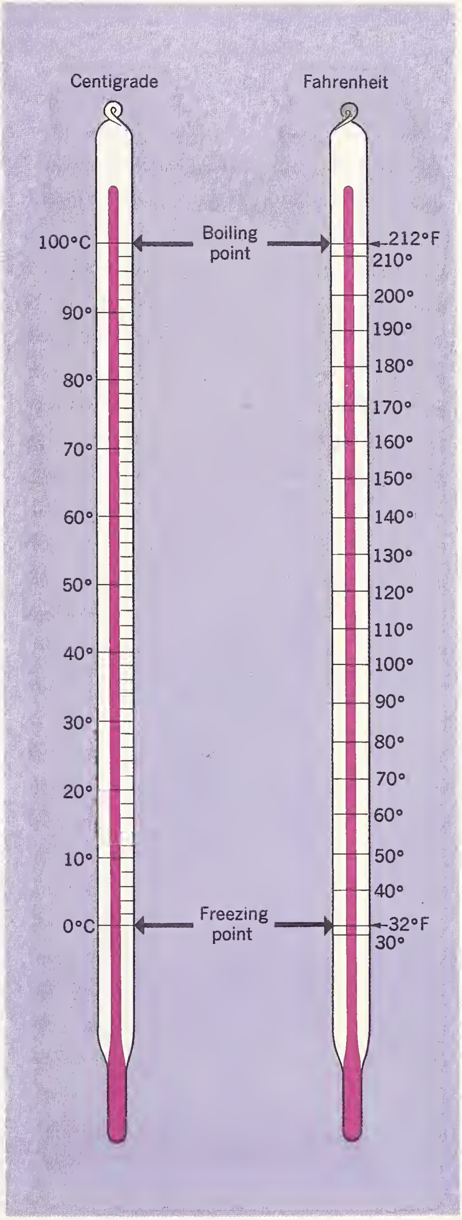
1. Can you explain why the water does not run into the flask?
2. Now heat the flask by holding it in both hands. What happens to the water in the tube? Why?

Heat adds energy to the molecules of a gas, as it does to solids and liquids. They move around faster than they did before. They bounce against the sides of their container. They also move farther apart from each other. Because their arrangement is not fixed, they are more active than the molecules in either a solid or a liquid. The gases expand. The molecules of gas in the flask push against the water in the glass tube, making it rise.

Most solids, liquids, and gases expand when heated and contract when cooled. Expansion is caused by the greater activity of molecules when heated, and contraction is caused by the lesser activity of molecules when cooled.

Measuring Temperature

Man has invented several scales for measuring temperature. On one scale the freezing point of water is labeled 0° and the boiling point of water is labeled 100°. Each degree on the thermometer is 1/100 of the distance between the freezing point and the boiling point of water. This is called a **Centigrade scale**. The Latin word *centi* means one hundred. Another scale is called the **Fahrenheit scale** (FAR-un-hyt). On this scale the freezing point of water is 32° and its boiling point is 212°. Scientists use the Centigrade scale. Can you find out why?



How Does the Thermometer Measure Temperature?

As the sun's rays strike the earth, the earth's molecules become more active. As air touches the warm earth, the motion of the molecules of air is increased, and they strike the thermometer bulb with greater speed. The molecules of the liquid in the thermometer, usually mercury, move more rapidly. They take up more room. The liquid expands. On a thermometer a scale such as the Fahrenheit or the Centigrade scale is marked off carefully to measure how much expansion takes place.

Can you explain what happens when the air becomes cooler?

When the temperature of water is 100° on the Centigrade scale, water molecules have gained so much energy that they are escaping rapidly into the air. A temperature of 0° on the Centigrade scale means that the average speed of the molecules of the water has slowed down so much that they are forming crystals of ice.

Temperature, then, is really a measure of how fast the molecules of a substance are moving. Some molecules move faster than others. Therefore

How does the picture below help you understand what is meant by the word *average?*

temperature is a measure of the *average* speed of the molecules. Does this mean that at a given temperature every molecule is moving at the same speed? Think about the word *average.* If the average height of sixth-grade boys is 4′10″, is every sixth-grade boy that size? Average is a measure of the middle; there will be some measurements above and some below the average.

Temperature is a measure of the average speed of the molecules. But we cannot measure this speed with a stop watch! Often the scientist must use an indirect way to measure something. The thermometer is an instrument used to measure in an indirect way the speed of molecules. Can you now explain what the thermometer is really measuring and why this tells us about the speed of molecules?

You remember that heat is the effect of the movement of all the molecules in a substance. Now you know that temperature is a measurement of the average speed of the molecules in that substance at a given time. Here is an example of the difference between heat and temperature. The Atlantic Ocean contains *more heat* than a cupful of boiling water, because the energy of *all* its molecules is greater than the energy of the few molecules in the cup of boiling water. But the cup of boiling water has a *higher temperature* than the ocean.

Using What You Have Learned

1. Try to think of a liquid you know that does not behave according to what you have learned about heating and cooling. Plan an experiment to show that this liquid is an exception.

2. Thermometers have different substances in them. What is used in your school nurse's thermometer? If there is a large outside theremometer in your town, find out what it contains.

3. For what purposes are the different kinds of thermometers used? What kind of thermometer would have to be used to measure temperatures during the winter in the Antarctic?

WHAT YOU KNOW ABOUT

Heat and Molecules

What You Have Learned

All matter is made up of molecules, which are in constant motion. Molecules are the smallest particles of a substance that have all the characteristics of the substance.

Molecules are too small to be seen, but scientists have much evidence that they exist and move. **Diffusion,** or movement of molecules away from a crowded area to an area of fewer molecules, gives some evidence. There is other evidence, such as the dissolving of a solid in a liquid; **conduction,** which causes cool molecules to become warmed when they are touched by heated molecules; and **radiation,** which is the transfer of heat energy to the molecules of a cool object.

Heating causes molecules to move faster and farther apart. Heating may change a solid to a liquid and then to a gas.

Cooling causes molecules of a substance to move slower and to become more fixed in their positions. Cooling may change a gas to a liquid and then to a solid.

Temperature is a measurement of the average speed of the molecules in a substance. Heat is the result of the movement of all the molecules in the substance. Thermometers, such as the **Centigrade** and the **Fahrenheit** thermometers, measure temperature.

Checklist of Science Words

Here are some science words you read about in this unit. Can you tell what you have learned about each one?

Centigrade scale	diffusion	radiation
conduction	Fahrenheit scale	

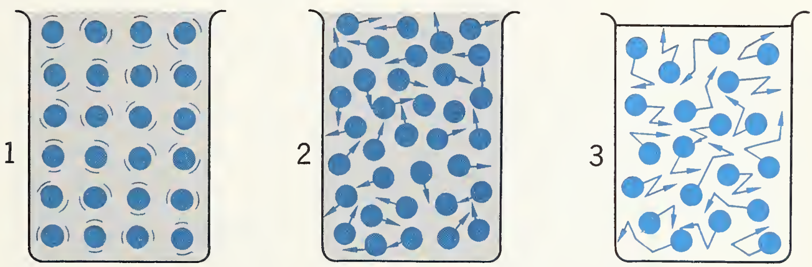
Explain Why

Use your knowledge of heat and molecules to explain why:

1. When air is warmed, it expands.
2. We receive heat from the sun by radiation.
3. Poor conductors are good insulators.
4. Metal handles on cooking utensils become hot.
5. Two thin blankets are warmer than one heavy blanket.
6. A thermos bottle can keep liquids either hot or cold.

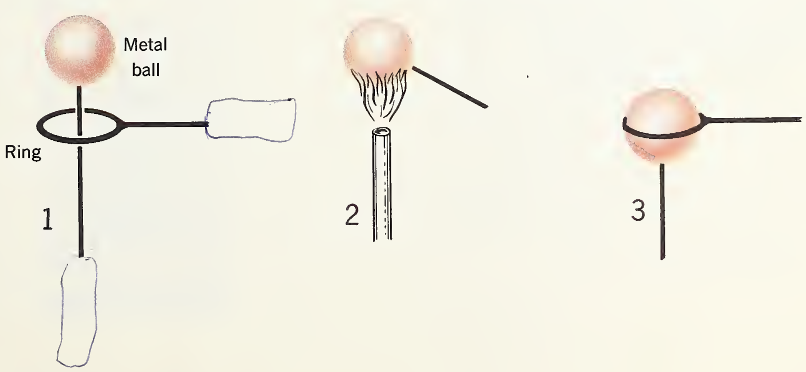
Can You Tell?

Look at the pictures below. Can you tell which jar contains a liquid, which a solid, and which a gas?



What Is Happening?

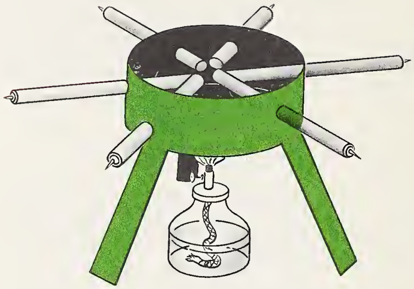
Can you explain what is happening in the pictures below?



YOU CAN LEARN MORE ABOUT

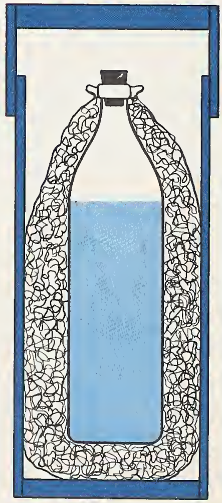
Heat and Molecules

You Can Find Out



Do metals conduct heat at different rates? Get 12-inch-long bars of different metals. Each bar should be of the same diameter. Next, cut a tin can as shown. Then punch holes in the side of the can—one hole for each bar. Insert the metal bars so that they touch at the center of the can. To the outside end of each bar attach a tack or nail with wax. Place a burner under the can holder so that the flame touches the inner edge of each bar equally. In what order do the tacks or nails fall off the bars? What does this show?

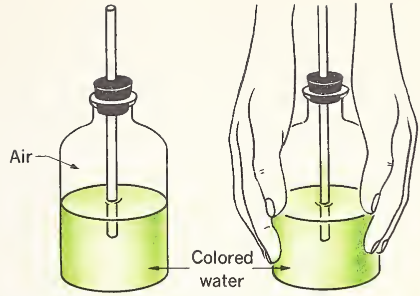
You Can Make a Thermos Bottle



You can use what you know about heat and molecules to make a thermos bottle. Make a cloth bag that will fit loosely around a bottle. Stuff the bag with kapok or cotton filler. Place the bag and bottle in a cardboard cylinder. Attach a string to the cylinder. Drinks can be kept hot or cold in this thermos bottle. Can you explain how?

You Can Make an Air Thermometer

Fill a bottle halfway with colored water. Place a glass tube about two feet long through a one-holed rubber stopper. Place the stopper in the bottle. Place your hands over the upper part of the bottle. Can you explain what happens in terms of the molecules of air?



You Can Read

1. *What Is Heat?* by Theodore W. Munch. Tells about sources of heat, heat and motion, and the importance of heat to man.
2. *Hot and Cold,* by Irving Adler. A more advanced book on the measurement, properties, and uses of heat.
3. *The Wonder of Heat Energy,* by Hy Ruchlis. Tells how various phenomena depend on heat. Suggestions for investigations are given.
4. *Heat,* by Bertha M. Parker, from the Harper and Row Basic Science Education Series. Experiments in the application of heat.
5. *Beginning Science with Mr. Wizard: Heat,* by Don Herbert and Hy Ruchlis. Some excellent experiments are given. The experiments are based on Mr. Herbert's popular television series.

3

Objects in Motion

Starting Things

Making Objects Speed Up

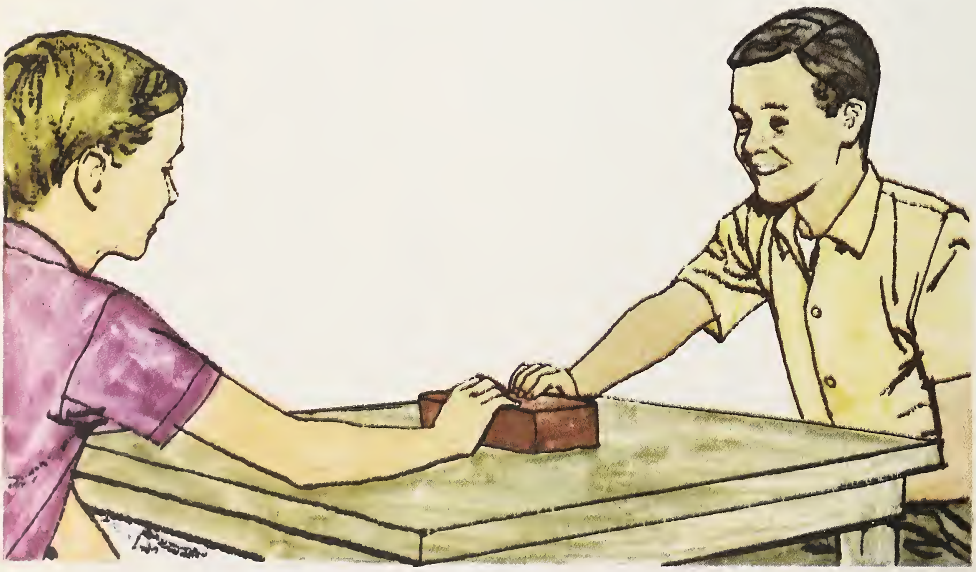
Putting an Object into Orbit

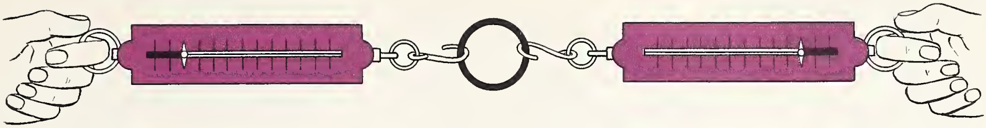
Some Other Orbits

Suppose you have a steel ball on your desk, and you want to make the ball move. How many different ways can you do this? In each way, you must *do* something to make the ball move. Objects do not start moving by themselves. They must be pushed or pulled. A push or pull is called a *force*.

Starting Things

Imagine a tug of war in which the teams are evenly matched. If both teams pull with the same amount of force, the rope does not move. You get the same result if you push hard on a brick from one side while a friend pushes equally hard on the opposite side. The brick does not move. As you can see, forces acting on an object do not always make it move.





See for yourself what happens when equal forces act against each other. Take a strong metal ring and hook two spring balances on it, as shown in the picture. The spring balances measure the amount of force you use. Now pull on the ring in one direction with a steady force of five pounds. Ask a classmate to pull on the ring in the opposite direction with a steady force of five pounds. Does the ring move?

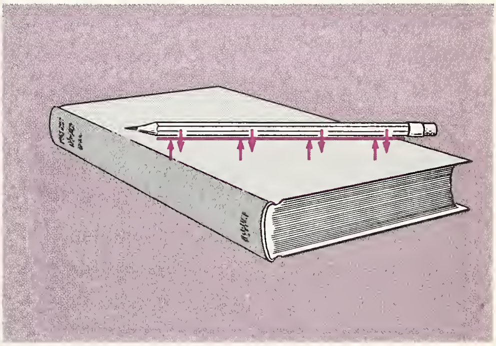
You could do many activities such as this and you would get the same result. An object at rest does not move if the forces on it are equal in size and come from opposite directions. These forces—forces acting on an object so that its state of rest or motion does not change—are called **balanced forces.**

Now try an activity in which you have your classmate pull with a steady five-pound force while you increase your force on the ring. What happens to the ring?

To make the object move, then, the forces acting on it must not be balanced. Somehow the balance of forces must be *upset*. One way of doing this is to change the size of one of the forces. In the metal ring experiment, you *increased* the size of one of the forces. Could you also make the ring move by *decreasing* one of the forces? Plan an experiment to find out. Perform your experiment. What were the results?

There are forces acting on all objects. A pencil resting on a book has forces acting on it. There is a downward force of gravity on the pencil. There is also an upward force exerted by the book on the pencil. The forces are equal and opposite. The pencil does not move.

How could you make the pencil move downward by reducing or removing one of the forces?



Objects Keep Going

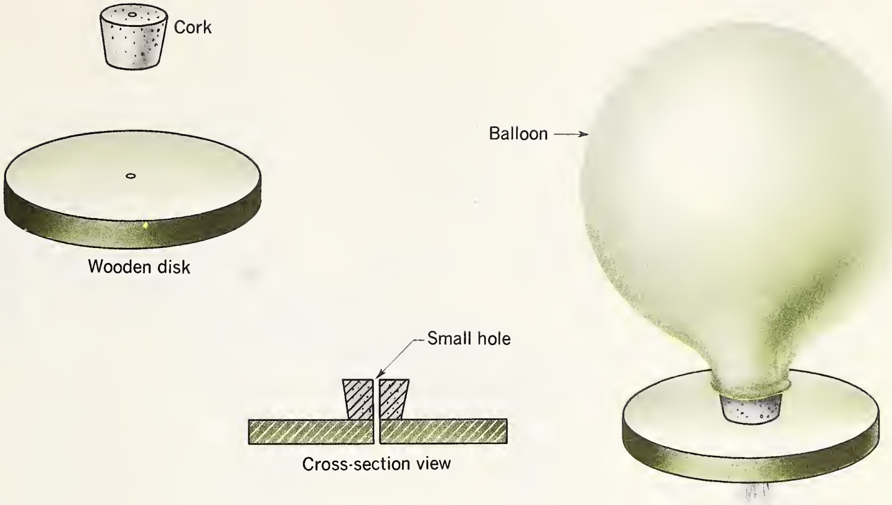
Scientists have always been interested in what keeps a moving object going. Galileo was the first to say that a moving object will continue to move at a steady speed and in the same direction as long as no force acts on it. This means that a sled that is coasting will keep on moving at the same speed unless some force acts on it. The same is true of a rolling skate or any moving object. But you know that objects do not keep going. They always stop. A coasting sled stops moving forward, even on level snow; otherwise the ride would last forever. A skate stops rolling, or you would lose a skate every time you started one going. What forces act on a moving object to stop it?

Forces that you cannot see may stop an object. These are **frictional forces** (FRIK-shun-ul), caused by the rubbing of one object against another. If you slide a book across a table, frictional forces from the table top act on the book to slow it down. Soon the book stops. Friction between a sled and snow stops the sled. Friction between a skate and pavement stops the skate. The frictional force opposes the motion of the object.

If you want to keep an object moving, you must apply a force that is equal to the frictional forces. If you can remove the frictional forces, you can keep an object moving at a steady speed as long as outside forces do not act on it. For example, a puck, or wooden disk, keeps moving on ice at a steady speed for a great distance once it is started. Can you tell why?

The model on the next page greatly reduces frictional forces. Air escaping from the balloon flows beneath the wood. Thus the wood floats on an air cushion. You can build such a device and set it in motion across a smooth, level floor or table. Blow up a balloon, cap it tightly to the cork, and push the wooden disk gently. Does the disk seem to move in a straight line? Does it seem to move at a *constant,* or steady speed?

Constant speed means that the disk moves the same distance during the first second as during the second, the same distance during the second second as during the third, and so on. Measure the motion of the disk to check for constant speed. You will need a device to measure equal **time intervals** (IN-ter-v'lz), and a method for measuring distances traveled. A pendulum clicks off equal time intervals when it swings by the lowest point. Set up a pendulum. Have one person rap the desk with a ruler every time the pendulum weight is straight down. Each time he raps, mark the position of the



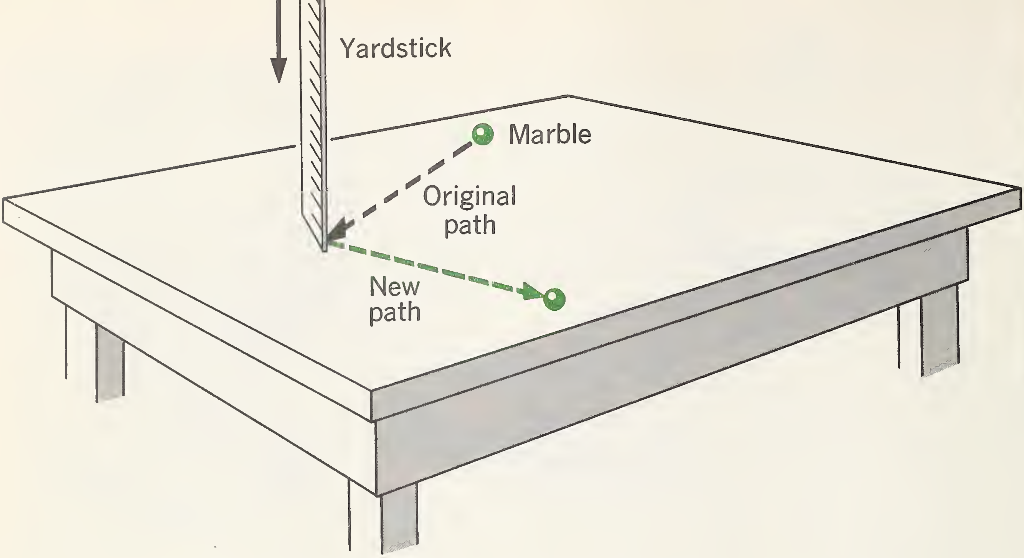
How does this model show you one way to reduce frictional forces?

disk. After several markings, measure the distances between marks. Are the distances equal? Did the disk move at a constant speed?

The ancient Greek scholars did not recognize frictional forces. Aristotle, for example, thought that an object keeps moving only if a force is steadily applied. He also thought that it was natural for objects to stop moving. Notice the difference between his ideas and those of Galileo. Galileo thought than an object keeps moving once it is started and *stops* only when frictional forces act on it.

Does Aristotle's idea seem to fit your observations? The moving objects that you see around you stop moving after a while if no force acts to keep them going. You do not start moving on roller skates and then coast forever on level ground without using more force. If you knew nothing about friction between your skates and the ground, Aristotle's idea would seem reasonable.

The forces acting on a steadily moving object are balanced. When the balance of forces is upset, the object may come to a stop or speed up. One way to upset the balance is to add a force, such as frictional force, that is opposite to the direction of the motion. But what happens if the unbalanced force is not *exactly* opposite to the direction of motion of the object? You can find out. Use the balloon disk



What happens when you apply to the marble a force that is not opposite to the direction of motion of the marble? How else might you show what would happen?

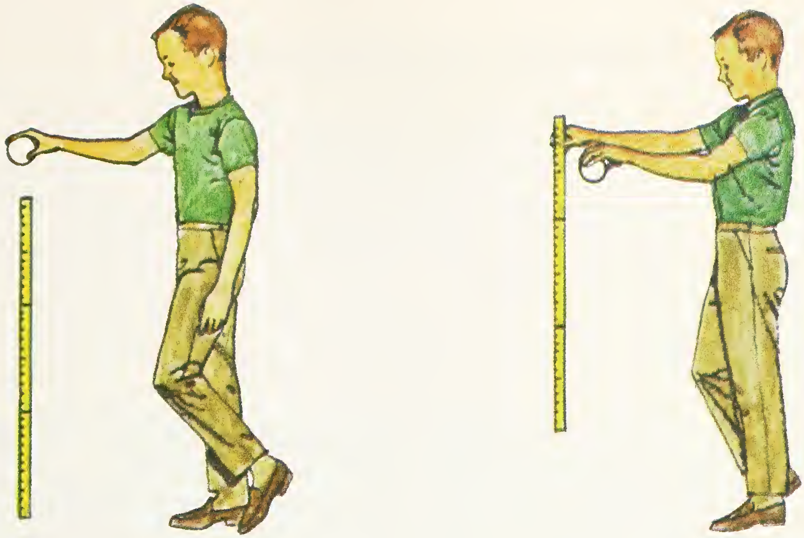
described on page 66, or simply roll a marble along a level surface. Apply a force on the disk or marble that is not opposite to the direction of motion. What happens?

Galileo and the Ship's Mast

Galileo wanted to demonstrate that an object keeps moving even though a force does not continue to act on it. In having this idea, he was one of the first to differ with Aristotle.

Imagine that you are coasting along in a car with the windows closed. You are holding a rubber ball directly over your head. Suddenly you let the ball go. Where would it land? In Aristotle's view, the ball would land *behind you,* because no force acts on the ball once it is released. If this were true, it would mean that a person standing outside the car would see the ball fall straight down. It would also mean that to a person riding forward, the ball would appear to fall backward.

In Galileo's time, scientists thought of doing this experiment on a ship. If the ship were *not* moving and a heavy object were dropped from the top of the mast, the object would land at the base of the mast. But Galileo said that even if the ship were moving, the object dropped from the top of the mast would land in the same spot.



These two pictures show the correct way to release the ball when doing each part of the activity described below. You will need an observer for the activity.

You can try a simple activity to demonstrate Galileo's idea. Set up a yardstick in an up-and-down, or vertical, position. Take a ball in your hand. Walk along holding the ball, and release it just as you pass the stick. Be sure you do not throw the ball. Just let go. Have your friends observe the path of the ball using the yardstick as a background against which to view the ball's motion. Try this several times to be sure of the ball's path.

Now try this. Walk along with the ball and carry the yardstick with you, holding it in a vertical position. Try to walk at a constant speed. Release the ball from near the top of the yardstick. Have your friends observe the ball's motion with the yardstick as the background for the observation.

Newton's First Law of Motion

Isaac Newton, an English scientist in the seventeenth and eighteenth centuries, stated the law of motion that summarizes the ideas in this section. Newton said that if *no* outside force is exerted on an object, the object will remain at rest or will continue to move in a straight line at constant speed. This statement of Newton's about the motion of objects is called the **First Law of Motion.**

Using What You Have Learned

1. For this experiment use the balloon disk described on page 66. Set it moving slowly—as slowly as you can. Exert a force on it that is just enough to stop the motion. Now start it moving slowly again. Exert a force in the same direction as the one you exerted before but greater than the first force. What happens?

2. For this experiment use a small, strong metal ring like the one shown in the picture at the left. Tie four pieces of rope to it. Have one person hold each rope. Have each person pull on his rope at the same time in such a way that the ring does not move. See how many different positions the four people can pull from without moving the ring. Describe the forces exerted on the ring in each case.

3. An object is moving at a constant speed. A force is exerted in the direction of the object's motion. At the same instant an equal force is exerted in the opposite direction. What happens to the motion of the object?

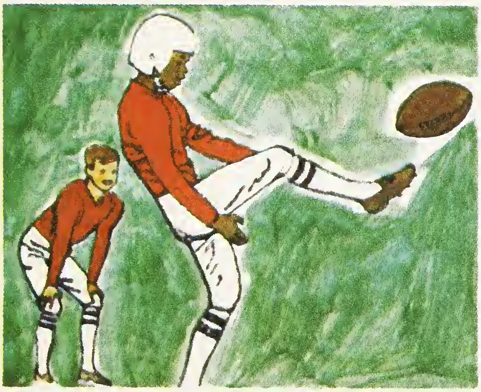
4. Imagine for a moment that you believe, as Aristotle did, that an object keeps moving *only* if a steady force is applied. How would you explain the motion of an arrow through the air after it is shot, or of a ball thrown through the air after it is released? In both cases, a force is used to *start* the object in motion. But in both cases the object *keeps* moving for a short time.

Aristotle thought he knew of a constant force that might keep the objects moving. He developed an explanation of this motion that fitted his ideas. Can you? Find out about Aristotle's explanation of the motion. How would you go about finding out about Aristotle's explanation? What sources would you use? How does Aristotle's explanation compare with the one you developed? What do you think makes an explanation a good one?

Making Objects Speed Up

If you apply a large enough force to an object at rest, the object starts to move in the direction in which the force is applied. You have seen this happen and made this happen many times. Push a book, and the book starts to move in the direction of the applied force.

When you swing a bat at a baseball, the ball moves in the direction of the force applied by the bat. When you kick a football, it sails into the air in the direction in which your foot was pointed. What are some other examples of how you make objects move?



How Can an Object Be Speeded Up?

What You Will Need

10 books of the same size

How You Can Find Out

1. Set up four piles of books, the first pile with one book, the second pile with two, the third with three, and the fourth with four.
2. Using one finger, exert a force on the bottom of the pile containing two books. The force should be just large enough to start that pile moving. Practice exerting that same amount of force on the pile several times so that the pile moves in exactly the same way each time. If you tie a spring balance to the books, you can measure the force required to move them.
3. Exert the same amount of force you used on the two-book pile on each of the other piles. Push on the bottom book each time. Notice what happens to the pile containing one book, then that with three books, then that with four books.

Questions to Think About

1. Each pile of books has a different mass. The four-book pile has a greater mass than the three-book pile. The three-book pile has a greater mass than the two-book pile. But you use the same amount of force in trying to move each mass.
   What is the relationship between how readily you can start an object moving and the mass of the object?
2. If you keep the force equal each time, which object is started more easily, one with a large mass or one with a small mass?
3. Exert a slight force on the two-book pile. Next exert a slightly greater force, then a still greater force, then one still greater. What happens to the object as you add greater and greater force to start it moving?
4. How is the motion of the object related to the size of the force exerted to start it moving?

Forces on a Moving Object

What happens to a *moving* object if you add a force in the same direction as the motion? For this activity use an object that will have very little friction with the surface on which it is moving. Objects such as a roller skate, a marble, or the balloon puck will work well for this activity. What kinds of surfaces do you think will work well?

Start the object moving. While it is moving, exert a force on it in the same direction as the motion by giving the object a sudden push. What happens to the speed of the object?

If you add a force to a moving object, the object speeds up. But so far you have added a force for only an instant, by one quick push. What happens when you add a force for a longer time?

What Happens If You Exert a Constant Force to a Moving Object?

What You Will Need

rubber band roller skate

How You Can Find Out

1. Attach the rubber band to the roller skate, as shown in the diagram. Exert a force on the roller skate by pulling on the rubber band. The length of the stretched rubber band gives you an idea of the amount of force you are using.
2. You must use a constant force. Therefore, the rubber band must be stretched to about the same length throughout the activity.
3. Start pulling the skate with the rubber band stretched just a little. Then keep it that way by continuing to pull with the same amount of force.

Questions to Think About

1. What happens to the skate if you keep exerting the same force?
2. What happens when you increase the force?
3. Does a very small force exerted constantly on a moving object make the object speed up continuously?

Tell where friction occurs in each picture. What does friction do in each of the pictures shown above? How is the friction overcome in each situation?

You have read about velocity and how it changes. The velocity of a moving object changes when the speed or the direction of the object changes. When the velocity of an object changes, the object is said to accelerate. In the activity showing constant force on the roller skate, the skate accelerated.

Since a constant force speeds up a moving object, you would expect things to go faster and faster just by applying a steady force. But you rarely see such continual acceleration. If you are riding a bike on level ground and exert a constant force, you accelerate for a short time. But after a while the constant force does not make the bicycle go faster. If it did, you would ride faster than the fastest jets after a while.

To find the explanation, we must think again about frictional forces. There is friction between the tires and the road, and between the chain and the axle. Friction increases as speed increases. In fact, friction becomes so great that you must exert a strong force just to keep going. Only in a frictionless world would you go faster and faster on your bicycle just by exerting a small, steady force.

Measuring Acceleration

You can measure the acceleration of a moving object. Imagine that you are riding a bicycle at a steady 5 miles per hour for 10 minutes. You are not speeding up or slowing down. Your acceleration is 0.

Next, suppose that you are riding at 4 miles per hour but speed up to 10 miles per hour after 1 minute. The increase in speed from 4 miles per hour to 10 miles per hour is 6 miles per hour in 1 minute.

A car is going 15 miles per hour. In 10 seconds it speeds up to 35 miles per hour. The acceleration is 20 miles per hour in 10 seconds. To find how much the car accelerates each second, you divide 20 by 10, which is 2. The *average* acceleration is 2 miles per hour each second. We say that the average acceleration is 2 miles per hour per second.

You are riding a bicycle at a slow 2 miles per hour. You speed up to 18 miles per hour in 4 seconds. The acceleration is 16 miles per hour in 4 seconds. To find the average acceleration each second, you divide 16 by 4. The acceleration is 4 miles per hour per second.

Here are some problems:

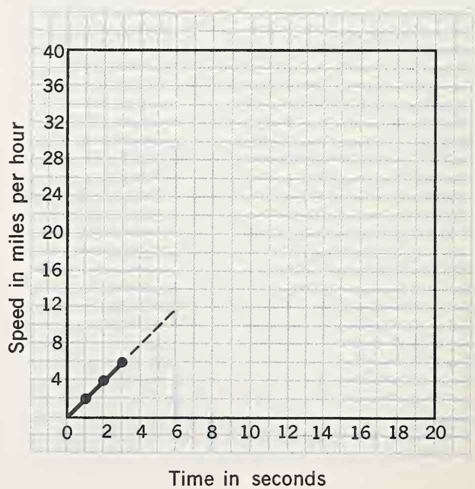
1. A speed skater going at 5 miles per hour speeds up to 20 miles per hour in 5 seconds. What is his average acceleration each second?

2. An automobile accelerates at a rate of 2 miles per hour per second. How long does it take the automobile to accelerate from rest to a speed of 20 miles per hour? Complete the graph below to find the answer.

Force, Mass, Acceleration

You have learned that the acceleration of an object in a certain direction depends on the size of the force, the direction of the force, and the mass of the object.

Complete this graph using the information given in problem 2. Be sure you do not write in the book. Instead, copy the graph in your notebook and complete it.



The mathematical relationship among force, mass, and acceleration worked out by Newton is called the **Second Law of Motion.** Some examples of this relationship follow.

1. If you double the force on a certain mass, the acceleration doubles.

2. If you use the same force on a mass twice as great as another mass, the acceleration is only one half as much for the greater mass.

3. To get the same acceleration for a mass twice as great as another mass, you must exert twice as much force as you would exert on the smaller mass.

Using What You Have Learned

1. If you push a wagon with twice as much force as your friend pushes a wagon of the same mass, how much more is your wagon accelerated than your friend's wagon?

2. A freight train with one engine pulls twenty loaded coal cars. It accelerates at 5 miles per hour each minute. A second engine is hooked on and pulls with the same force as the first engine. What is the new acceleration?

3. Imagine exerting on a heavy adult running away from you the same force you exert on a child running away at the same speed. What difference will there be?

4. Hook a spring balance to a roller skate and try to pull with a steady force. Notice the acceleration. Now firmly tie a brick to the skate. Pull with an equal force. Is there a difference in the acceleration? Why?

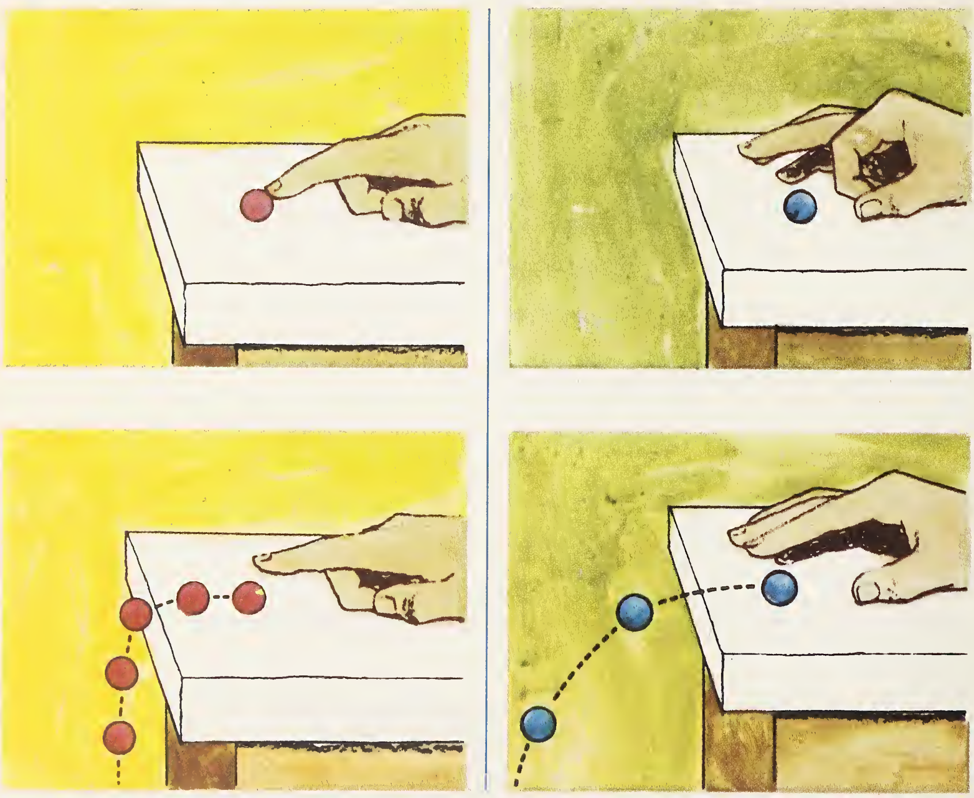
5. Try to add a second brick to the skate. Tie it on firmly. Pull with a force equal to that exerted in Activity 4. What happens? Why?

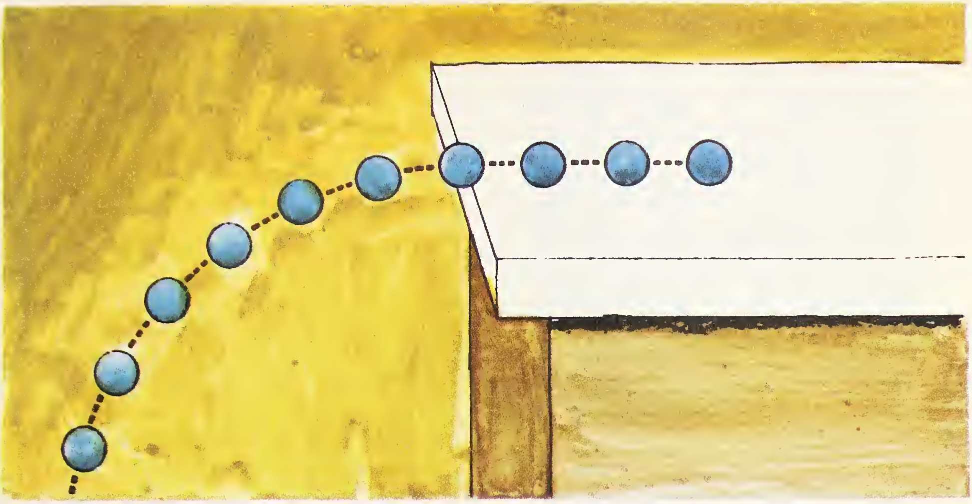
6. Explain how Newton's Second Law of Motion enables scientists to determine the size of the force that is needed to put a satellite into orbit and to change its direction, speed, and position.

Putting an Object into Orbit

Suppose you were to nudge a marble off the edge of a table. You know that it would fall. The force of gravity would draw the marble toward the earth. But would the marble land near the table or away from it? Draw a diagram to show the path that you think the marble would take.

Now suppose you were to flick the marble off a table straight out into the air. The marble, of course, would again fall to the floor. Where would it land this time? Would it fall just beneath the table top or some distance away? Draw a diagram to show the path that you think it would take.



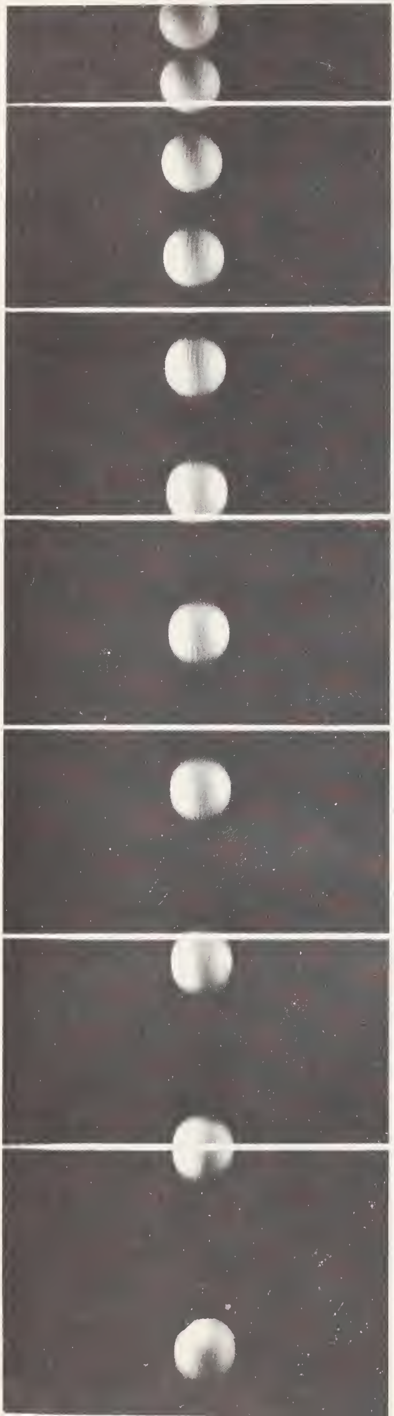


Observe the path a marble would travel if it were rolling on a frictionless table top.

The first marble had only one motion—downward. But the second marble had two motions—outward and downward. The flick of your finger provided the force to start the marble moving outward. Once set in motion, the marble, like any other object, moved outward at constant speed. (The air exerts some frictional force, but not enough to affect the marble much in this activity.) Constant speed in an outward direction means that the marble moved outward the same distance every second.

The diagram above shows how the marble would travel if it were rolling along on a frictionless table top. The position of the marble is shown at intervals of one-tenth of a second. Notice that the distance traveled in each fraction of a second is the same. This is the motion you expect according to Newton's First Law of Motion, which says that if no new force is exerted on an object, the object will remain at rest or will continue to move in a straight line at constant speed.

But when you flicked the marble off the table, there was downward as well as outward motion. Immediately after it left the edge of the table, the marble was pulled toward the earth by the force of gravity. This force acts in a vertical direction. As you know, the actual direction of movement of the marble was the result of both forces.



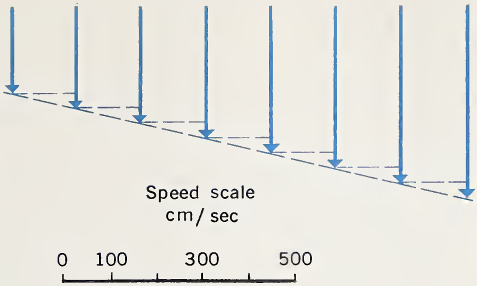
Here is a series of photographs, taken at equal time intervals, of a falling golf ball. The time interval between each photo and the next is $\frac{1}{30}$ second. The white lines are six inches apart. Notice that the ball is accelerating as it falls. How far does it fall in the first fraction of a second? In the next? If the distance is greater for the same period of time, then the speed must be greater.

$$\text{speed} = \frac{\text{distance}}{\text{time}}$$

The ball is speeding up at a steady rate. We can say that it is accelerating uniformly. For every interval of time the amount of acceleration is the same.

According to Newton's Second Law of Motion, things speed up uniformly only when there is a constant force. Gravity is the force making the object fall, and the force of gravity is constant. It always exerts a steady force on any object near the surface of the earth.

The outward force and the downward force on the marble or on the golf ball act independently of each other. The outward force does not change the downward force, and the downward force does not change the outward force.



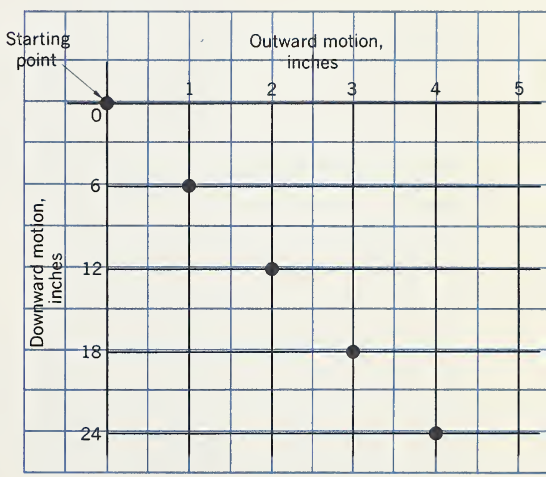
Look at the diagram above. It illustrates, as does the photograph on page 80, the motion of the falling golf ball. We can study the motion of the ball by finding out (1) the size of the force that acts on the ball and (2) the direction of the force acting on the ball during each time period. We can measure the distance the ball falls during a given time period by measuring between the golf balls on the photograph, and then we can divide this distance by the time period. This will give us the length of the velocity vector. The direction of the velocity vector is the direction the ball moves from one photograph to the next. The diagram above represents the distances the ball falls between flashes of the camera. The spaces between the white lines shown on the photograph on page 80 represent 6-inch distances, and the time between flashes is 1/30 of a second. What do you notice about each velocity vector?

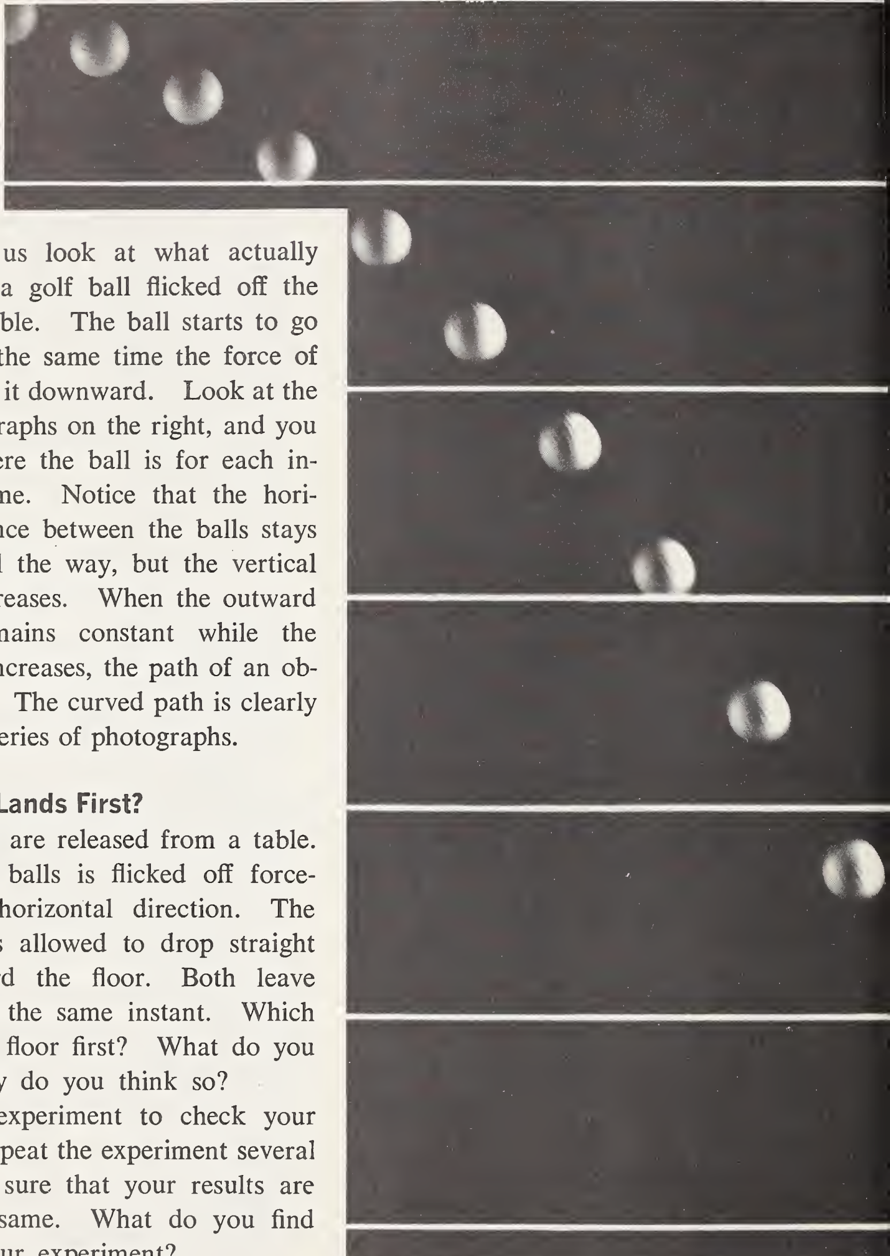
Can you tell why centimeters were used in the scale rather than inches?

A Graph That Can Never Be

Suppose that gravity did not accelerate objects and that sizes of downward vectors did not change. One short push would start the ball downward. Let us see where the golf ball would be after each fraction of a second.

In this graph of an imaginary situation, the dots represent the positions of the ball at the end of equal time intervals. At the end of the first fraction of a second the golf ball would have moved out one inch and down six inches. At the end of the next fraction, it would be out another inch and down another six inches. What kind of a path would the marble have taken? What would be the shape of the path?





Now let us look at what actually happens to a golf ball flicked off the edge of a table. The ball starts to go out, but at the same time the force of gravity pulls it downward. Look at the flash photographs on the right, and you will see where the ball is for each interval of time. Notice that the horizontal distance between the balls stays the same all the way, but the vertical distance increases. When the outward velocity remains constant while the downward increases, the path of an object *curves*. The curved path is clearly seen in the series of photographs.

Which Ball Lands First?

Two balls are released from a table. One of the balls is flicked off forcefully in a horizontal direction. The other ball is allowed to drop straight down toward the floor. Both leave the table at the same instant. Which one hits the floor first? What do you think? Why do you think so?

Plan an experiment to check your answer. Repeat the experiment several times to be sure that your results are always the same. What do you find out from your experiment?

Orbits

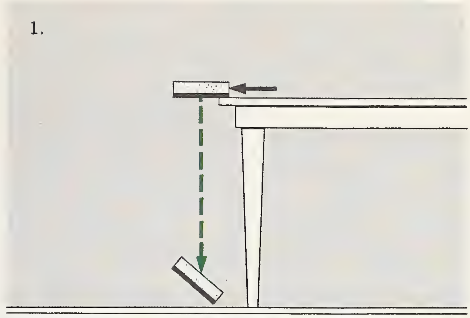
An orbit is the path of one object around another. Think of an eraser in the following paths:

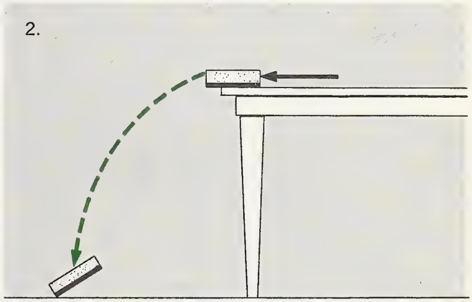
1. Push the eraser off the table with *no* horizontal speed. The path of the eraser is straight down toward the center of the earth.

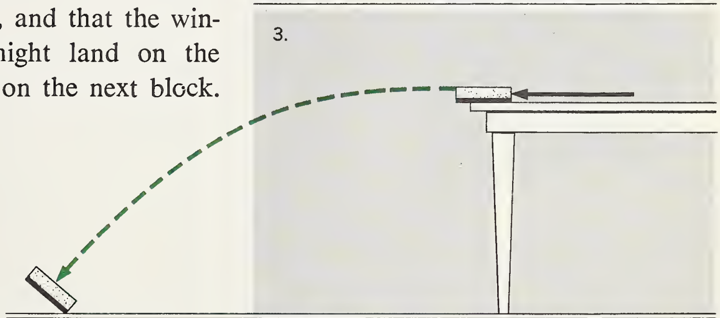
2. Shoot the eraser at a slow horizontal speed. The eraser moves outward before striking the floor.

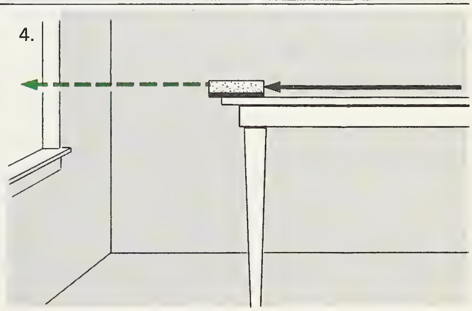
3. Shoot it at a slightly faster speed. If you really shoot the eraser fast enough, it might go across the room before striking the floor.

4. Now imagine that you can shoot the eraser still faster, and that the window is open. It might land on the school yard or even on the next block.



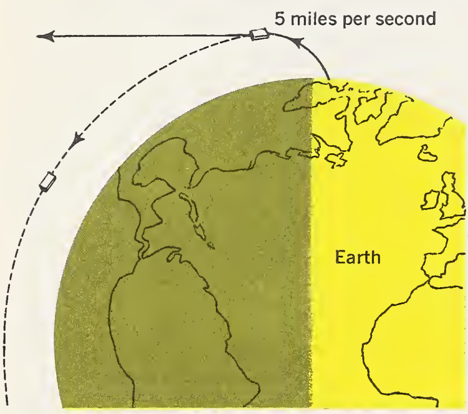






5. Imagine that you now have a powerful eraser shooter, and you shoot the eraser even more forcefully. It might go as far as the next town before striking the earth. What might the path look like?

6. This time imagine that you shoot the eraser at 5 miles per second. The eraser keeps falling to the earth as it did in 1 through 5, but the horizontal speed is so great that the earth curves away from the falling eraser as fast as the eraser falls toward the center. The eraser is in orbit around the earth.



To put an object in orbit around the earth, the object must be given a horizontal speed of about 5 miles per second. The object is first shot straight up to clear the earth's atmosphere quickly. Then the *horizontal* force is applied to put the object in orbit. It does not matter whether the object is an eraser or a rocket. If it is shot out horizontally with a speed of 5 miles per second, it goes into orbit around the earth.

Space Capsules

The earth's atmosphere thins out rapidly as the distance from the earth increases. In fact, one-half the atmospheric volume is under the altitude of 3½ miles. An object traveling in space is far higher than this. Therefore, the frictional forces of air are small, and the laws of motion seem easier to understand.

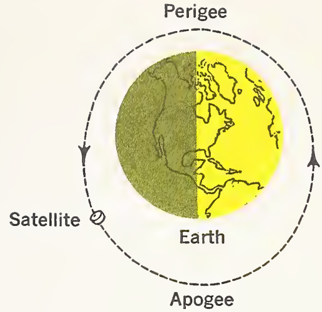
A tremendous force is needed to accelerate a space capsule so that it clears the earth's atmosphere quickly and reaches a horizontal speed of 5 miles per second. But once this speed is reached and the object is above the atmosphere, only one force continues to act on the capsule—gravity. No fuel is needed to keep the capsule in orbit. The object is pulled toward the earth, but because of the great horizontal speed and the lack of frictional forces to change the horizontal speed, the earth curves away from the capsule as rapidly as the capsule falls.

While the capsule is orbiting, only very small forces are needed to change its position. The force of a water pistol is enough to make the capsule tilt. This force is enough to make the capsule accelerate to much higher speeds. Small rockets have enough force to make the object head back to earth.

Most orbits are not perfect circles. They are slightly longer in shape. This

shape is called an **ellipse** (ih-LIPSS). The point on the ellipse nearest the earth is the **perigee** (PEHR-uh-jee). The farthest point is the **apogee** (AP-uh-jee).

As you know, many man-made satellites have been sent into orbit around the earth. They have to reach a speed of 5 miles per second, or they will fall back to earth. But if they reach a speed as high as 7 miles per second, they are traveling too rapidly to be in an earth orbit. The capsule then is very little affected by the earth's gravitation. It goes into an orbit around the sun. Many capsules have reached 7 miles per second, called **escape velocity**, and have entered into orbits about the sun.



Using What You Have Learned

1. Imagine that you are in a space capsule that is falling toward the earth. You hold out your arm and drop a ball. What path will the ball take, as seen by an observer on the ground?

2. What special steps are taken to prevent space capsules from burning up when they re-enter the atmosphere?

3. It is difficult to study the accelerated motion of an object that is falling freely. To "slow" the motion, you can roll the object down a slope. This is what Galileo did in his studies of falling objects. Take a smooth board six feet long and put books under one end to lift the board two inches off the floor. Then roll a smooth cylinder down the slope and mark the position after each second. Figure out a method of marking the position of the cylinder after each second. Compare the distance traveled during the last second to the distance traveled during the first second.

PATHFINDERS IN SCIENCE

Sir Isaac Newton

(1642–1727) England

The story is told that one day in 1666, while sitting in a garden, Isaac Newton saw an apple fall from a tree. He thought about falling objects. Why did the apple fall down instead of up? If apples fall down, why doesn't the moon fall down?

Isaac Newton was able to get new meanings from facts. For example, to Newton the apple became the moon. He knew that the moon and other large heavenly bodies seemed to move in regular orbits month after month, year after year. He wondered what force kept them there. Was it the same force that caused the apple to fall from the tree?

Why do the planets go around the sun? Why don't they fly off in straight lines? Perhaps a greater force—the sun's—pulls them out of their straight-line paths. Why does the moon circle the earth?

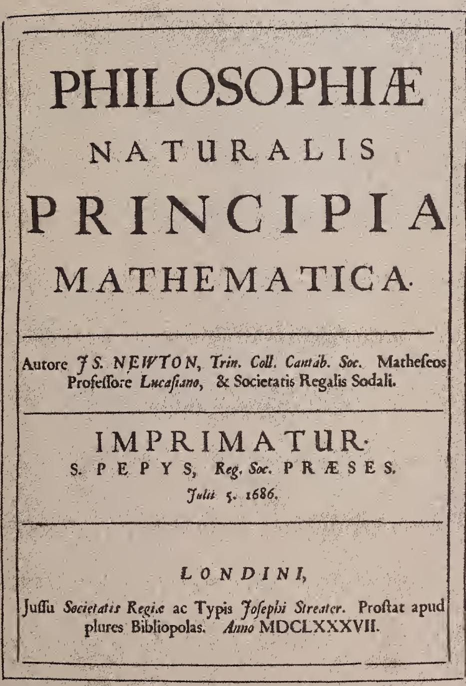
Copernicus and other astronomers thought that the circular motion of the heavenly bodies was a "natural motion," just as the falling down of any object not held up by something was a natural motion.

Newton questioned this idea. He formed his own idea: the only natural motion objects have is that they move uniformly along a straight line. This idea later became the basis of Newton's *First Law of Motion.*

Next Newton thought, if the planets orbit the sun and the moon orbits the earth in circular motions, then something must get in the way of their normal straight-line motion. There must be a force that causes them to go off their straight-line paths into the circular paths.

The moon, he thought, must be revolving around the earth because the earth attracts it. And at the same time things on the earth's surface fall toward the earth. He reasoned that the force that keeps the moon in its monthly orbit around the earth is the same force that makes apples fall earthward.

After much mathematical figuring, Newton decided that gravitational pull is strong or weak depending on the distance an object is from the earth. This idea laid the groundwork for his *Law of Universal Gravitation,* which says that massive objects pull each other harder than less massive ones. The pull is greater between objects near each other than between objects that are far apart. Newton believed that these two statements were also true for objects in space; that is why he used the word *universal,* meaning "everywhere in the universe."



PHILOSOPHIÆ
NATURALIS
PRINCIPIA
MATHEMATICA.

Autore *J. S. NEWTON*, *Trin. Coll. Cantab. Soc.* Mathefeos Profeffore *Lucafiano*, & Societatis Regalis Sodali.

IMPRIMATUR.
S. PEPYS, *Reg. Soc.* PRÆSES.
Julii 5. 1686.

LONDINI,

Juffu *Societatis Regiæ* ac Typis *Jofephi Streater*. Proftat apud plures Bibliopolas. *Anno* MDCLXXXVII.

Galileo and others could not find the answer to why the moon, under the earth's gravitational pull, does not fall into the earth as does an apple. Newton's answer was that it is falling every moment toward the earth.

The moon falls around the earth following the earth's curvature. It also pulls back on the earth. In fact, according to his universal law, every object, even a tiny meteor far out in space, must pull every other object. The apple that fell from the tree pulled the earth at the same time that the earth pulled the apple. But the apple's pull was so weak that it was not noticed. In the same way, the moon pulls the earth. And the earth pulls the moon. But because the moon is very far away, and also in motion, it cannot fall into the earth. The gravitational force between the earth and the moon is just enough to keep the moon in orbit about the earth.

Newton spent almost twenty years testing, proving, and improving his early theories before publishing his *Principia*, which contained his *Law of Gravitation* and the *Laws of Motion*. This book presented so much new scientific knowledge that some of the greatest triumphs of human thought can be traced back to it.

Isaac Newton contributed greatly to his own time and to future generations.

Some Other Orbits

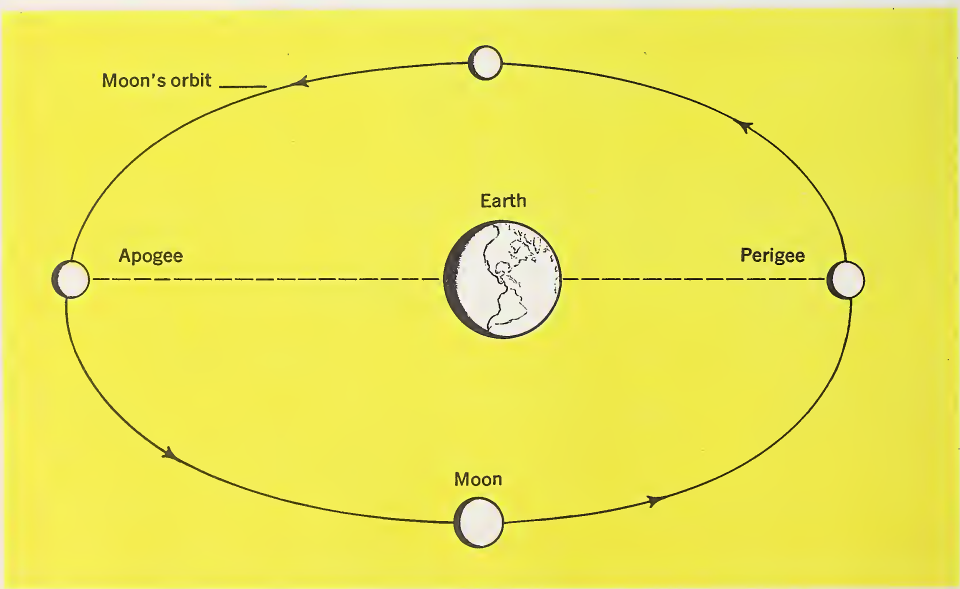
The Moon

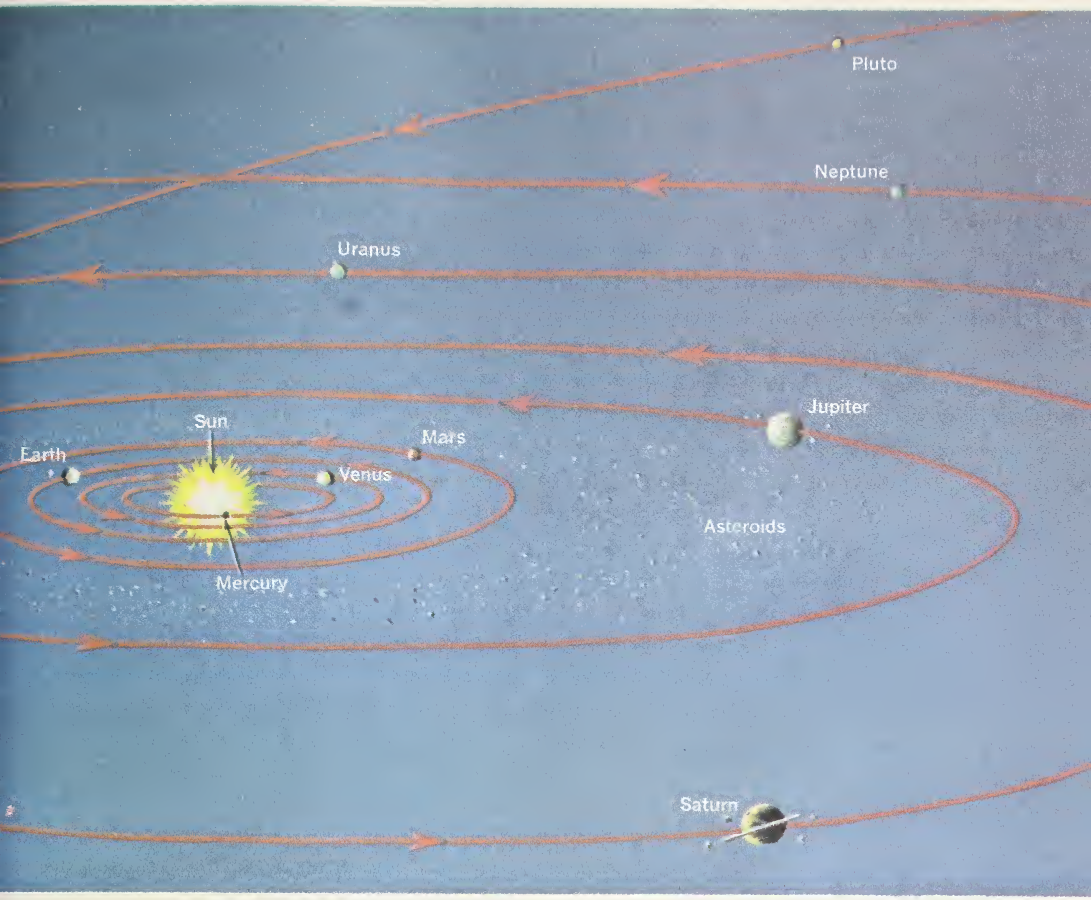
The moon orbits the earth in about 27 days at an average distance of about 240,000 miles. At perigee it is about 32,000 miles closer to the earth than it is at apogee. It travels at about 2,300 miles per hour in its elliptical orbit about the earth.

Like a launched eraser or a space capsule, the moon is always falling toward the earth. But its speed is great enough to keep it in orbit. Below you see a picture of the moon's orbit about the earth.

The Earth

The earth is in orbit around the sun, as are all the planets in our solar system. The sun is a much more massive body than the earth; therefore, there is a greater gravitational attraction between the sun and nearby objects than between the earth and objects that it attracts. For the earth to orbit the sun, it must travel at a higher speed than that of an object orbiting the earth. The earth moves at an average speed of about 18 miles per second in its solar orbit.





How does Pluto's orbit differ from the orbits of the earth and other planets? How does the gravitational attraction between the sun and the different planets vary?

Comets and Their Orbits

Also moving around the sun are objects called **comets** (KOM-its). Comets travel along very long ellipses. Actually, there are hundreds of thousands of comets, but they rarely come close enough to the sun to be seen from earth. Astronomers think that comets were far out in the solar system when the earth and the other planets were formed. They may be many miles in diameter.

Now and then a comet flashes in toward the sun. As it nears the sun, the outer layers of the comet melt off

This is a photograph of a comet seen on October 19, 1911.

and form a traveling cloud of tiny particles that we can see. This cloud is the comet's tail.

Comets have very little mass compared to the planets. Therefore, according to the laws of motion, they are easily accelerated. Sometimes a comet passes near the massive planet Jupiter. The strong gravitational attraction of this planet changes the comet's path, putting it into a different orbit.

When the astronomer studies the planets, the stars, and the bits of dust between them, he finds that everything is always in orbit. A tiny asteroid is in orbit around the sun. So are the planets. The sun orbits the center of our galaxy. Nearby galaxies orbit each other. All objects in space have a motion resulting from some force that started the object moving when it was created. Gravitational forces accelerate the objects in motion in curved, elliptical paths.

All objects in the universe seem to follow the same laws of motion.

Using What You Have Learned

1. Ask a friend to sit in a wagon and hold on to the sides. Start to pull the wagon suddenly. Notice what your friend must do to keep from falling out. Explain your friend's reaction by using the laws of motion.

2. At the earth's surface the acceleration of a freely falling object is 32 feet per second each second. That is, after one second, a freely falling object is traveling 32 feet per second. How fast is it traveling after two seconds? After three? After four?

3. When you round a sharp curve in an automobile, you must brace yourself, or you fall over. Why?

4. A ball is dropped from a very tall building. Do you think it keeps accelerating at 32 feet per second per second for the entire trip? Why?

5. A spacecraft on a trip to the moon requires fuel for launching, no fuel for the travel through space, but fuel again for the landing. Why is it necessary to use fuel for a safe, soft landing?

6. Find out about Galileo's experiments with freely falling objects.

7. Galileo investigated many fields of science. Find out about some of his important discoveries in astronomy.

8. Give practical examples of Newton's First and Second Laws of Motion.

9. Find out how Newton's Laws of Motion are applied to the design of rifles.

10. Explain why you reach a constant speed on a bicycle even though you continue to push on the pedals.

WHAT YOU KNOW ABOUT

Objects in Motion

What You Have Learned

All objects seem to follow the same laws of motion.

To start an object moving, the **balance of forces** must be upset. A moving object will continue to move unless a force acts to stop it. **Frictional forces,** caused by the rubbing of one object against another, may stop an object. Isaac Newton's **First Law of Motion** states that an object at rest will remain at rest, and an object in motion will continue to move in a straight line at constant speed, as long as no other force is exerted on the object. If enough force is added to a moving object, the object will accelerate. The acceleration of an object in a certain direction depends on the size of the force, the direction of the force, and the mass of the object. The mathematical relationship of force, mass, and acceleration as worked out by Newton is called the **Second Law of Motion.**

If an object is accelerated to a horizontal speed of 5 miles per second, it will go into orbit around the earth.

If an object reaches a horizontal speed of 7 miles per second, called **escape velocity,** it will escape from the earth's gravitational effect and go into an orbit around the sun.

Checklist of Science Words

Here are some science words you read about in this unit. Can you tell what you have learned about each one?

apogee	comets	escape velocity
balanced forces	ellipse	perigee

Matching Test

Write the numbers 1 to 7 on your paper. Next to each number write the letter of the word or words described.

1. Forces that are equal in size and come from opposite directions.
2. Forces caused by the rubbing of one object against another.
3. If no outside force is exerted on an object, the object will remain at rest or will continue to move in a straight line at a constant speed.
4. If you double the force exerted on a certain moving mass, the acceleration doubles.
5. Forces represented by arrows.
6. The point of an orbit closest to the earth.
7. The point of an orbit farthest from the earth.

A. First Law of Motion
B. apogee
C. vectors
D. perigee
E. Second Law of Motion
F. frictional forces
G. balanced forces

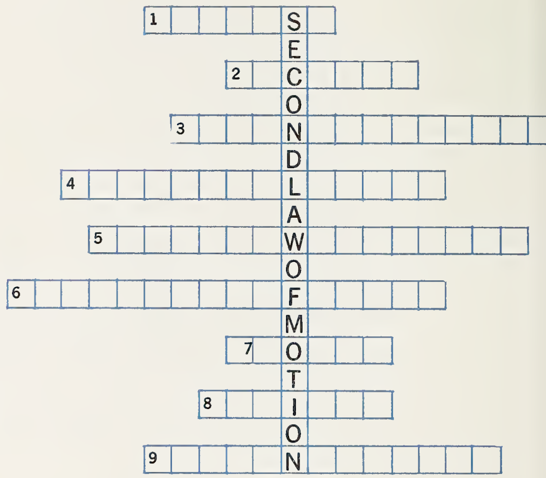
Can You Tell the Law of Motion?

Look at the pictures below. Which law of motion is illustrated in each?

Objects in Motion

What Are the Words?

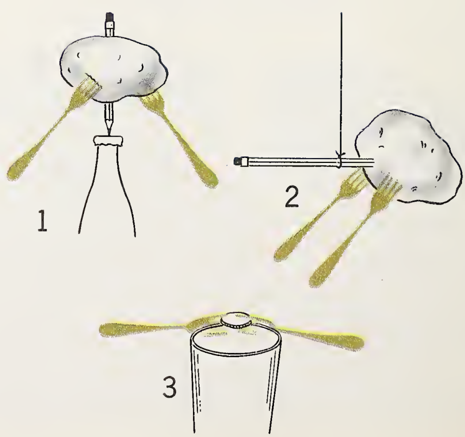
Write the words in your notebook.



1. The shape of most orbits.
2. These arrows tell how large a force is and in which direction it acts.
3. Forces that are equal in size and that are exerted in opposite directions.
4. The horizontal speed at which an object is traveling too rapidly to go into orbit around the earth: about 7 miles per second.
5. The statement that if no other force is exerted on an object, the object will remain at rest or continue to move in a straight line at constant speed.
6. Forces caused by the rubbing of one object against another.
7. The point on an elliptical orbit farthest from the earth.
8. The point on an elliptical orbit closest to the earth.
9. The equal periods marked off by the swings of a pendulum.

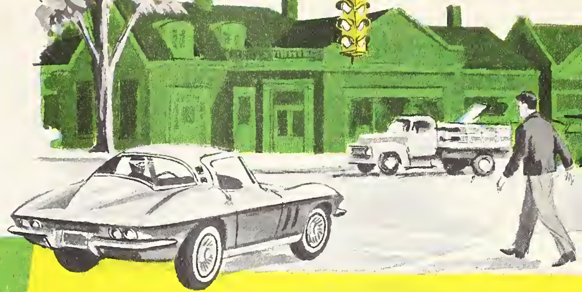
Try This

Use what you know about balanced forces to make the pictured setups.



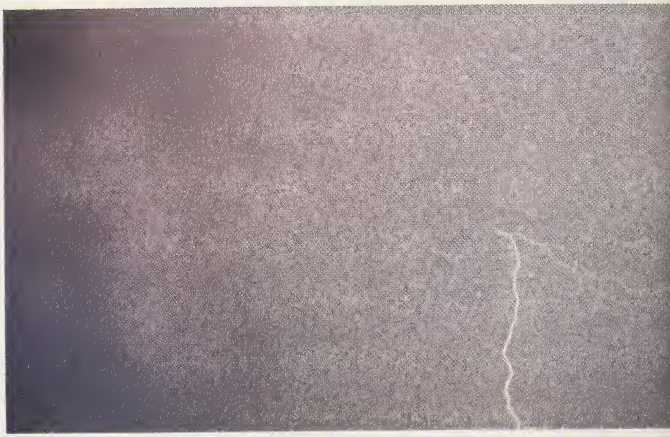
Balanced or Unbalanced Forces?

Look at each picture and tell whether the forces are balanced or unbalanced. Which laws of motion are illustrated?



You Can Read

1. *Your World in Motion,* by George Barrow. Investigations of motion in air, water, and heat.
2. *Orbit,* by Hy Ruchlis. Tells about Newton's laws and shows how these principles are at work not only in ordinary activities but also in space flight.
3. *Things That Spin: From Tops to Atoms,* by Irving and Ruth Adler. A well-illustrated book that discusses various types of motion and compares them with the top.
4. *The Quest of Isaac Newton,* by Barbara and Myrick Land. Newton's discoveries and their importance to modern science.
5. *Isaac Newton,* by Patrick Moore. Newton's career and the relationship of his work to that of other men of his time.


4

Electricity and Electronics

Electricity and Electrons

Electricity and Magnetism

Electrons are responsible for the pictures on your television screen, the music that comes from your radio, and the flash of lightning in a thunderstorm. Understanding why electrons act the way they do and how they can be put to use is a new branch of science called electronics.

Electricity and Electrons

You flip a wall switch and your room is flooded with light. You push a button and a ringing bell instantly tells of your presence at the door. You turn a knob and a picture appears on the television screen. These are all effects of electricity at work.

What causes these effects? What is electricity? What is its source? Why do some materials allow it to move freely, and why do others not? How does electricity produce heat, light, and sound?

Finding the answers to these "whats" and "whys" and "hows" has been the work of many scientists for centuries. The forming of hypotheses, the making of models, and the performing of experiments to find out more about electricity continue today.

This unit will introduce you to the many wonders of the electrical world. You will learn much that scientists have learned about electricity.

Electricity and Matter

You know that all the things in this world are composed of matter. Gases, such as the air we breathe, are matter. Liquids, such as the water we drink, are matter. Solids, such as the bricks with which we build, are matter. Matter is just another name for substance, of which all things that exist are made.

Wherever matter exists in any form, electricity also exists. Matter and electricity cannot be separated. How have scientists shown that electricity is always joined with matter? Or, better still, how can you show this?

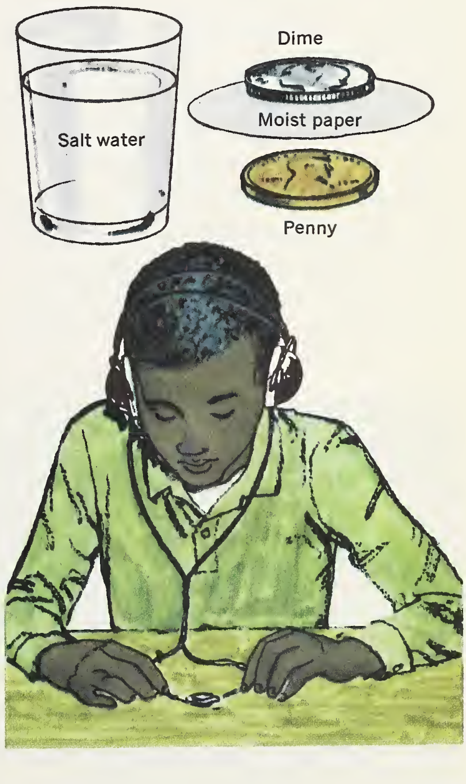
On a day when the humidity is low, drag your feet across a thick carpet. Then slowly place your finger very near a metal doorknob or radiator. The tiny spark you see or the slight tingle you feel is an effect of electricity. You have shown that electricity is present in matter by rubbing matter against matter—your shoes against the carpet.

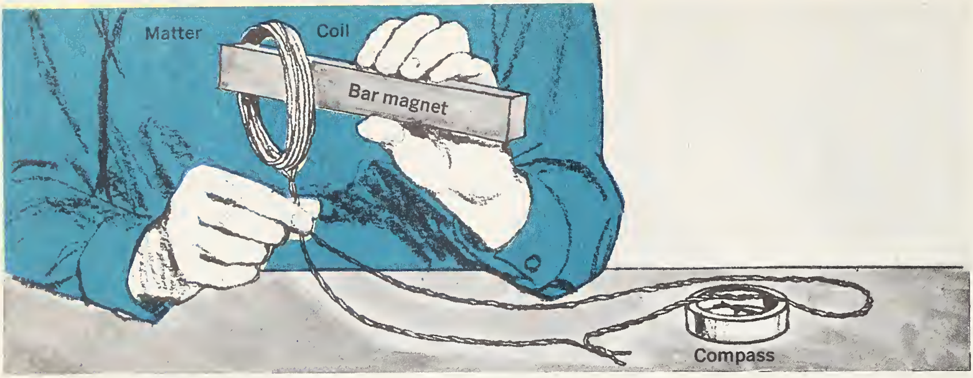
Can you think of other ways to show electricity in matter by producing *friction?* What other ways can you think of? Try some of them.

You can show that electricity is present in matter by chemical action. Cut a piece of brown wrapping paper to the size of a nickel. Moisten the wrapping paper with water in which some salt has been dissolved. Sandwich the moist wrapping paper between a penny and a dime. Touch the dime with one tip and the penny with the other tip of the wires connected to a pair of headphones, as shown in the picture. The "click" you hear is an effect of electricity. What are some of the things in everyday use that show by *chemical action* the presence of electricity? How can you tell these things work chemically?

Can you tell what will happen when the boy touches the knob as in the picture?

Tell how the boy is producing an electrical effect by chemical means?





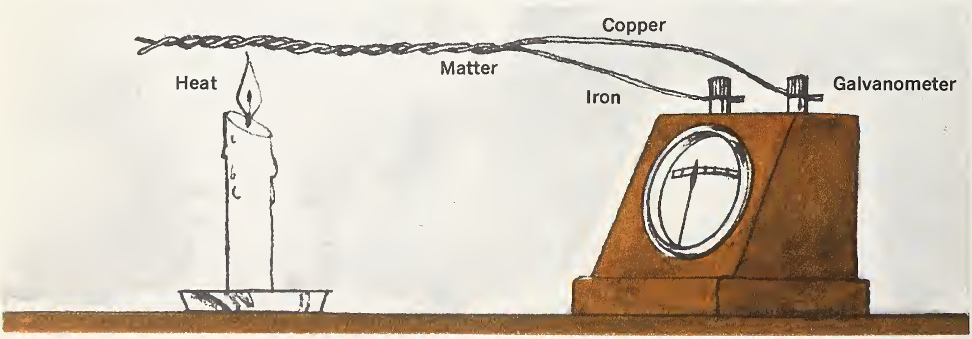
Tell how the boy is producing an electrical effect by means of magnetism.

Connect the bare ends of a coil of insulated wire to each other, as in the picture above. Place a length of the wire over a magnetic compass. Rapidly move a bar magnet in and out of the wire coil.

If an electrical effect is produced, it will be detected by the movement of the compass needle. Can you see the needle move as you do the activity?

Tightly twist together the ends of a piece of copper and a piece of iron wire. Connect the free ends to a **galvanometer** (gal-vuh-NOM-uh-ter). Heat the ends red hot with a candle. The heat causes electrical charges to move within the matter. That the electrical charges are moving is shown by the movement of the needle in the galvanometer.

Tell how an electrical effect is being produced by means of heat.



You can also show the presence of electricity in matter by using light. Connect a selenium photovoltaic cell or a silicon solar cell to a milliammeter. You can get these materials at radio and television or photographic supply stores.

Let a flashlight or other bright beam of light fall on the cell. Try blocking the light beam with your hand. Notice that the milliammeter reaches its highest reading only when the beam of light falls directly on the cell. Can you think of a photographer's device that makes use of this **photoelectric effect?**

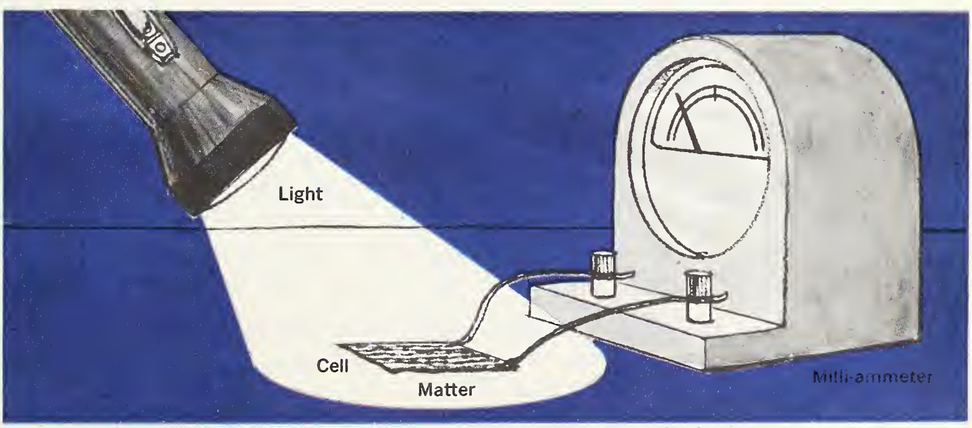
In each of the various tests you made—frictional, chemical, magnetic, thermal, photoelectric—matter was used in some form for the production of an electrical effect. Electricity is a property of all matter.

Energy

You know that electricity is present in matter. You have shown this by the five tests you performed. Since electricity is already present in matter, it cannot be generated.

However, *electrical energy* can be generated. *Energy* is the ability to move something by pushing or pulling. It is the ability to do work. Work certainly was performed by electricity in the five tests. How do you know this? Very simply, you saw meter needles move. You heard "clicks" produced in your headphones. And you saw and felt sparks or mild shocks. Because you acted on the electricity in matter in some way, you caused electrical energy to be generated to do this work. Can you think of other ways in which you can show that electrical energy is generated?

Tell how an electrical effect is being produced by means of light.



Matter

Why must matter always be present wherever electrical energy is generated? To find out we will study matter in more detail.

Matter can be divided into smaller and smaller amounts. For example, a large bar of metal can be cut into small pieces with a hacksaw. A file will reduce these small pieces to smaller pieces that are as fine as dust. A grinding mill will break the metal dust into such small particles that each becomes invisible unless viewed with a powerful magnifying glass.

Can this division of matter be continued to get smaller and smaller pieces, without limit? Scientists of the past thought not. They thought there was a smallest particle of matter that could not be divided further. They gave this smallest particle of matter the name *atomos,* which means "the indivisible." From this Greek word *atomos* we get our modern word **atom.**

Atoms

The scientists of the past were right in saying that there was a smallest particle that could not be divided, but they stopped too soon. The atom is the smallest particle of matter that can be identified as a chemical element. These atoms are called, for example, oxygen, sulphur, iron, gold, and uranium. Today, we know that atoms can be divided. They, too, are formed of smaller particles.

In this photograph you can see the atoms in tungsten crystal.

Hundreds of experiments have proven that an atom cannot be a solid. It is mostly empty space. At the center of the atom is a tiny particle forming a core. In the space around this core swiftly revolve other extremely small particles. These revolving small particles also rotate on their own axes. Can you describe the difference between revolving and rotating?

In the scientists' models, the atom resembles our solar system, but its scale is very, very small. There is a central sun with its revolving and rotating planets, and in between—nothing but empty space!

The Nucleus of the Atom

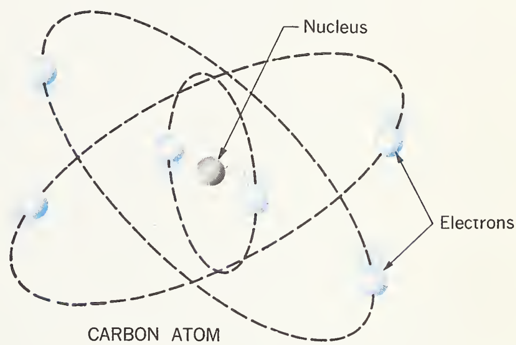
You will remember that the part forming the core of the atom is called the *nucleus*. *Nucleus* is the Latin word for "kernel." The nucleus is responsible for almost the entire mass of the atom, just as the sun is responsible for almost the entire mass of the solar system. However, the nuclei of different elements differ in mass.

Electrons

The word **electron** was derived from the Greek word for "amber." Amber was associated with electricity in ancient times.

The particles revolving around the nucleus and rotating on their own axes are the electrons. All the electrons in all the atoms of matter in the universe are identical.

Here is a picture of a carbon atom. How many electrons does the carbon atom have?



What can you tell about the mass of the uranium nucleus compared to the mass of 238 hydrogen nuclei?

Joseph John Thomson

(1856–1940) England

The activity that occurs within atoms is fascinating. Perhaps even more fascinating is the story of how scientists developed a model of the atom without touching, seeing, or weighing it.

The tool that first enabled scientists to unfold the secrets of the atom was the Crookes tube. This tube, which came in many different shapes, was developed by Sir William Crookes. It was made of glass. At each end of the tube were two metal plates. The tube had a thin neck, connected to a vacuum pump, so that air could be pumped out of it. Both plates were connected to an electrical circuit. One plate was negative (the cathode), and the other plate was positive (the anode). As air was pumped out of the tube, glows of different colors and shapes filled the tube. Since the glows seemed to come from the cathode plate, they were called *cathode rays.*

Joseph Thomson was very much interested in cathode rays. He decided to do a series of five experiments with the Crookes tube.

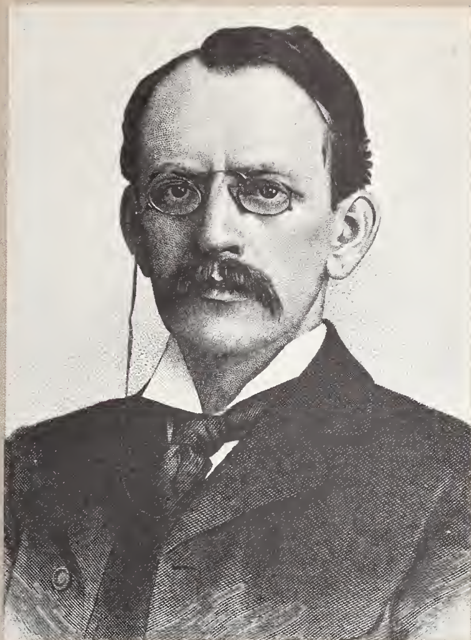
First Thomson coated the anode plate with a fluorescent chemical that he knew would glow when struck by cathode rays. Then he put a metal cross in the rays' path. A shadow of the cross appeared on the anode. This showed that cathode rays travel in straight lines.

In his second experiment, he put a paddle wheel in the path of the cathode rays. The rays started the wheel turning. He now knew the cathode rays were made up of moving particles of matter.

Third, he placed the north and south poles of a magnet on either side of the tube. He saw that the particles that made up the cathode ray were bent by the magnet. They bent in the direction of the positive plate, which showed that they had a negative electrical charge.

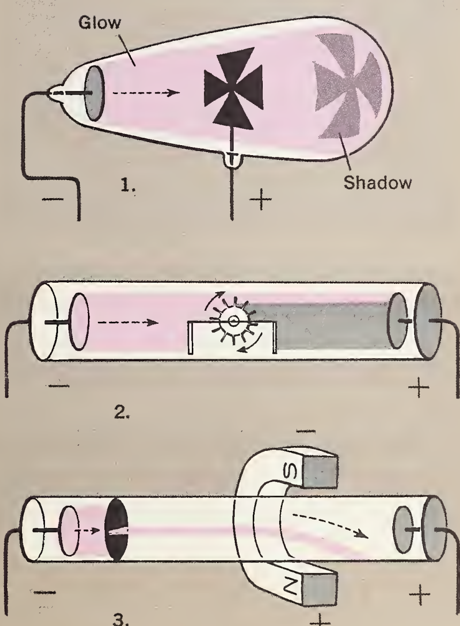
In his fourth experiment, he put electrically charged plates on either side of the stream of particles. By measuring the amount of charge necessary to bend the stream, Thomson was able to figure the weight of the particles. He found they were very, very light.

In the fifth experiment, he used different cathodes and put traces of different gases in the tube. The particles behaved in the same way each time. Thomson



then hypothesized that these particles were part of all matter and were always the same.

For nearly 100 years, scientists thought that the atom was the smallest unit of matter, that there was nothing inside the atom, and that it could not be divided. In 1887, Thomson reported his findings. He said that cathode rays are particles of negative electricity that come from within the atom. He also stated that atoms can be divided by the action of electrical forces. The particles from all kinds of atoms weigh the same and carry the same charge of negative electricity.



Thomson had discovered particles that could be found within every atom. He called these particles *electrons.* He suggested a model of the atom based on his observations. It was called the raisin-bun model. The atom was a solid ball (the bun) with a positive electrical charge. Within the ball were negative electrons (the raisins) scattered to form rings.

Other scientists followed Thomson, and their findings changed the model of the atom. But Thomson remains one of the first to unfold the secrets of the atom.

Electric Force

In the solar system planets tend to move out, or away from the sun, in a straight line. This tendency is called **inertia** (in-ER-shuh). *Gravitational forces* tend to pull the planets *inward,* or toward the sun. Because these forces are balanced, the planets remain in orbits around the sun, keeping the solar system intact.

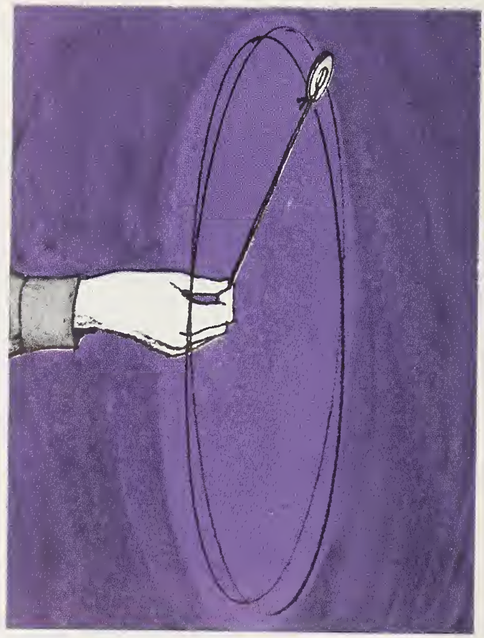
Electrons in the atom also have inertia. They tend to move out, or away from the nucleus, in a straight line. Because the speed of electrons is much greater than the speed of the planets, the gravitational pull of the nucleus does not affect the electrons as much as the gravitational pull of the sun affects the planets.

The tendency of electrons to move away from the nucleus is very strong. Size for size, inertia is much stronger for the electrons than it is for the planets.

Try this. Tie a large iron washer to a broken rubber band. Whirl the iron washer in a circle. As you increase the speed of the revolving washer, it exerts more force on the rubber band. What happens to tell you this?

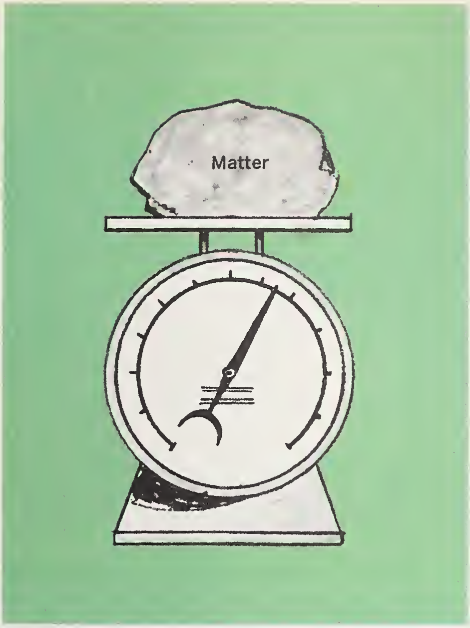
Gravity is too weak a force to hold the swiftly revolving electrons in orbit. With gravity alone, the atom would fly apart. The force that holds the atom together is many, many times more powerful than gravity. It is electric force.

All matter possesses two properties. To one of these properties we give the name **gravitational mass.** Gravitational mass is the cause of gravitational



force. To the other property that all matter possesses we give the name *electricity.* Electricity is the cause of electric force.

The extremely small particles of the atom are responsible for electric force. All the visible effects of electricity—the



Matter possesses gravitational mass, which exerts gravitational force. How is this idea shown in the picture above?

driving of huge electric trains, brilliant strokes of lightning, the powerful illumination of gigantic searchlights—are the results of forces produced by these tiny particles.

Scientists do not yet know the basic material composing the particles of atoms. But they do know much about the behavior and effects of these particles. For this reason we can describe, at present, only the behavior and effects of electricity. This is all we know about gravity, too.

Attraction and Repulsion

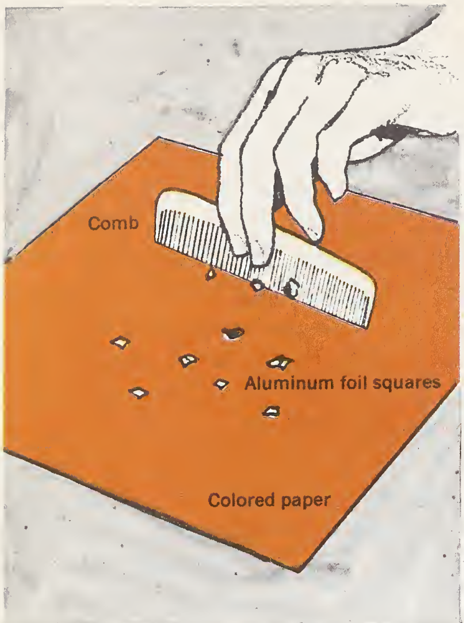
We can compare electric force to gravitational force because each has the ability to move objects. But there are differences in how these forces behave.

For example, in the solar system, the gravitational force of the sun attracts the planets. The gravitational forces of the planets attract the sun and each other. There is only one kind of gravitational force, the force of *attraction*.

In the atom, the nucleus electrically attracts the electrons. The electrons, in turn, electrically attract the nucleus. But the electrons, instead of attracting one another, *repel* one another. There are, then, *two* kinds of electric forces. One kind is a force of *attraction*. The other kind is a force of *repulsion*.

You can demonstrate the difference between gravitational force and electric force for yourself. Get a sheet of colored paper. Place the paper on a table top. Obtain a thin piece of aluminum foil, a pair of scissors, and a plastic or hard rubber comb.

Hold the aluminum foil over the colored paper. Using the scissors, cut the foil into very small squares. Let them fall on the colored paper. Why do the squares fall downward? Are any of the foil squares repelled upward? What does this tell you about the force of gravity exerted by the gravitational mass of the earth?



Now vigorously stroke your hair several times with the comb. Rapidly bring the teeth of the comb near the small squares of foil on the colored paper. What happens to the squares? Does this action show that electric force can be stronger than gravitational force? Why? Are some of the foil squares violently repelled from the comb? What does this tell you about electric forces?

Has the stored electrical energy in the comb performed work? What was the work? What had to happen before the stored energy could do work?

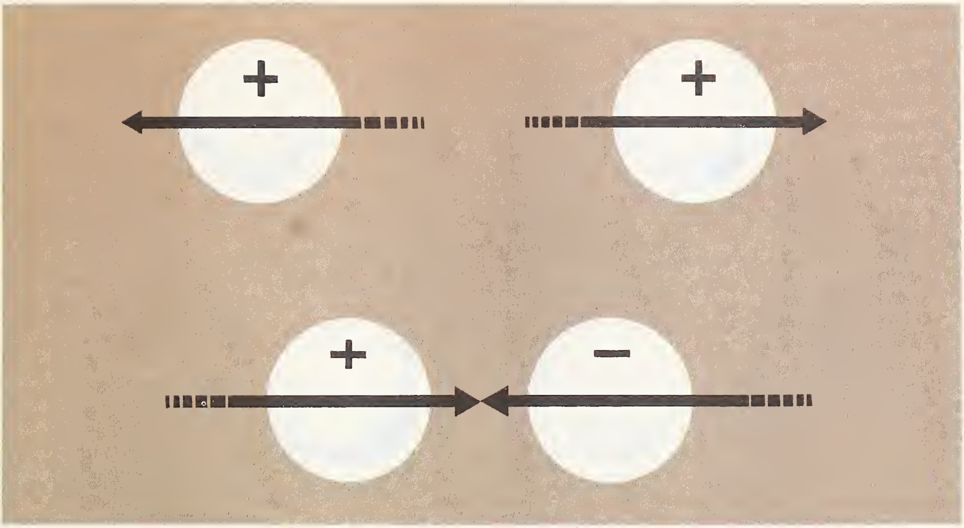
Kinds of Electricity

How are the two kinds of electric force, attraction and repulsion, explained?

Suppose we form hypotheses to provide the answer. We will assume that there are two kinds of electricity. We will then hypothesize that like kinds of electricity exert a repelling force on each other. This hypothesis will account for the observed electric force of repulsion. If we also hypothesize that unlike kinds of electricity exert an attractive force on each other, we can account for the force of attraction that we have observed.

These hypotheses seem reasonable. You can test them by referring to the facts you have learned. You know that all electrons are identical. Each electron carries the same kind of electricity. But all electrons repel each other. Therefore, *like kinds of electricity exert a repelling force on each other.*

Again, you know that an attractive electric force exists between the nucleus and the electrons. This is the attractive force that holds the atom together. But like kinds of electricity repel. Therefore, the electricity of the nucleus and of the electron must be of different kinds. Thus, we may state that *unlike kinds of electricity exert an attractive force on each other.*



What kinds of electric force are shown above? How can you tell each kind?

Have our hypotheses met the test of known facts? Could you form any other hypotheses about electricity and electric forces? Could you then test them by the known facts about the behavior and effects of electricity? Try to do so.

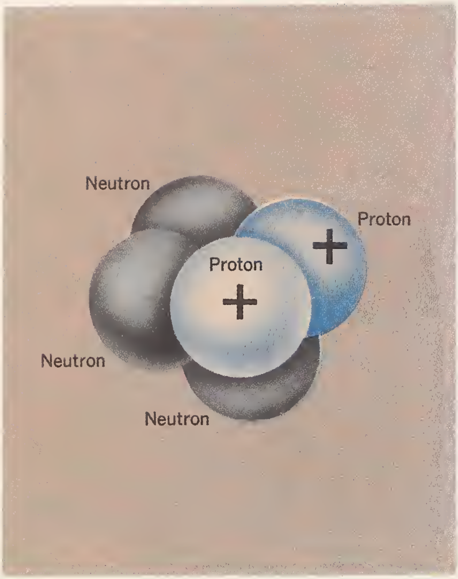
Two Kinds of Electric Charges

Since there are two kinds of electricity, they have different names. The kind of electricity of the electron is called *negative electricity,* simply to identify it and distinguish it from the other type. The electricity of the nucleus is therefore called *positive electricity.* You have already learned that the symbol for negative electricity is a negative, or minus, sign (—). The symbol for positive electricity is a positive, or plus, sign (+).

Neutrons and Protons

We have been discussing the nucleus of an atom as though it were a single particle. But long before atomic bombs or nuclear reactors were even imagined, scientists discovered that the nucleus is a cluster of small particles.

The small particles forming the nucleus are called **neutrons** and **protons.** Neutrons and protons are much heavier than electrons. In fact, each one weighs 1,840 times as much as



What can you tell about the nucleus of the atom above? How many electrons would the atom have?

an electron. This is why the nucleus is responsible for almost the entire mass of an atom. How does the total mass of an atom compare with the mass of a feather?

Neutrons are peculiar particles. Unlike protons and electrons, they possess gravitational mass, but they do not possess any electric charge. Because electric force is not exerted by the neutrons, these particles are of little interest to us in our present study of electricity.

Protons possess both gravitational mass and electric charge. Protons are the actual carriers of *positive electricity*. The nucleus has positive electric force because it contains protons.

Atomic Structure

We learned earlier that an atom is made up of a nucleus around which electrons revolve. Now, we have looked inside the nucleus and found a cluster of neutrons and protons. Protons carry positive electricity, and electrons carry negative electricity. Neutrons are electrically neutral: that is, they exhibit neither positive nor negative electricity. There are still other particles in the atom that you will learn about in later grades.

Electric Charge

We shall now become familiar with a word we have used and will continue to use. The word is **charge.** It is used both as a noun and as a verb.

As a noun, *charge* means the quantity or amount of something—for example, money, gunpowder, or electricity. A service charge is the amount of money to be paid for the performance of work. A powder charge is the quantity of gunpowder placed in the barrel of a cannon. A charge of electricity is a quantity of electricity. You placed a charge of electricity on the comb when you stroked your hair in the aluminum-square experiment.

As a verb, the word *charge* means to place a quantity or amount of something on or in something. You charge the cannon when you place gunpowder in the barrel. You charge a comb with electricity when you pass it through your hair. When a cannon is fired, it is discharged. When electricity is removed from a charged object, it is discharged.

The word *charge* can be used as a noun. For example, a gun crew places a charge in a gun. *Charge* can also be used as a verb. When a shell is placed in a gun, the gun is charged. Below, the gun is fired; it is *discharged*. Now apply the word *charge* to electricity, using it as a noun and as a verb.

Elementary Charges

It is believed today that electrons and protons are particles of matter that cannot be divided further. For this reason they are called **elementary particles.** It also is believed that the charges of electricity that these particles carry cannot be reduced. No smaller quantities of electricity have ever been observed. Scientists call these smallest quantities of electricity **elementary charges.**

The electron, of course, carries an elementary charge of negative electricity. The proton carries an elementary charge of positive electricity. Scientists have found that the elementary charge of negative electricity is exactly equal in quantity to that of the elementary charge of positive electricity. The positive charge of the proton and the negative charge of the electron produce the same amount of electric force. But how are the charges different?

The only difference between the positive and negative charges is that like charges of electricity repel and unlike charges attract each other.

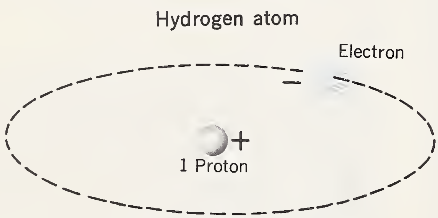
The Neutral Atom

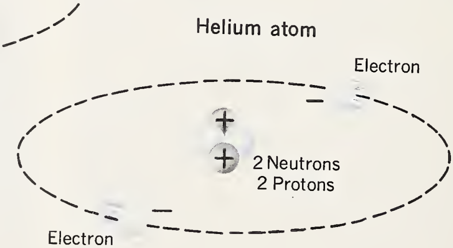
Scientists have known for a very long time that the atoms of each element are quite different from the atoms of all other elements. For example, the nucleus of the lightest element, hydrogen, contains only 1 proton. The nucleus of the helium atom, the next lightest element, contains 2 protons and 2 neutrons. Uranium, the heaviest natural element, contains 92 protons and 146 neutrons. The number of particles in the nuclei of the atoms is fixed by nature.

Certain man-made elements, such as einsteinium, have nuclei that contain even more protons and neutrons than those of natural elements. As far as is now known, these elements do not occur naturally on earth; but they can be manufactured in machines called **accelerators** (ak-SEL-er-ay-terz).

Each atom usually contains the same number of electrons and protons. For example, the helium atom contains 2 electrons and 2 protons. Therefore, atoms usually contain the *same quantity of positive and negative electricity* and are therefore **neutral.**

How many electrons does the neutral uranium atom contain? How many positive and how many negative elementary charges does it then hold?

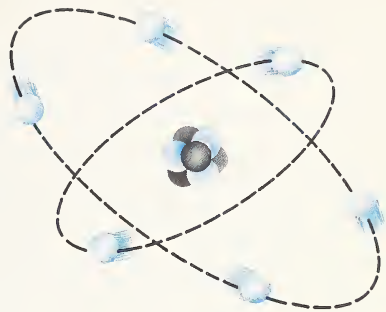




Equal Quantities of Electricity

The element carbon provides a good model for studying the effects of equal quantities of the two kinds of electrical charges in the atom. (Carbon is used in the ordinary flashlight battery.)

The carbon atom contains 6 protons within its nucleus and 6 electrons revolving about the nucleus. The atom thus holds 6 elementary positive charges and 6 elementary negative charges. The quantities of positive and negative electricity in the atom are equal to each other.



CARBON ATOM

Imagine now that one electron, not attached to any atom, wanders near the carbon atom. The wandering electron should be attracted by the nucleus of the carbon atom. Why? At the same time the wandering electron should be repelled by the electrons of the carbon atom. Why?

The elementary charges of both negative and positive electricity exert equal forces. What effect does the carbon atom have on the wandering electron?

Since the electric forces of attraction and repulsion of the carbon atom are of the same strength, they cancel each other. Therefore, the carbon atom has no effect on the wandering electron.

Another way of thinking about this situation is to consider the charges themselves. The carbon atom contains 6 negative elementary charges, which together have a total value of —6 (minus six). The atom also holds 6 positive elementary charges, which together have a total value of +6 (plus six). If we add the two total charges, —6 and +6, the sum is, of course, zero. *The neutral carbon atom appears to have no charge at all.*

All neutral atoms are electrically balanced. The electric forces exerted by the protons in the nuclei are cancelled by the electric forces exerted by the electrons. Mathematically, the total positive (+) and negative (—) charges of neutral atoms add up to zero. Thus *matter normally produces no electrical effects.*

Work and Electricity

You have seen that matter, made up of billions and billions of charged elementary particles, normally does not have the ability to do work electrically. Certainly your desk, your chair, and your eraser do not, by themselves, produce electrical effects. Matter gains electrical energy, which is the ability to do work electrically, only as a result of certain actions performed on it.

What are these actions? What actions did you perform on matter to produce electrical effects? You dragged your shoes across a carpet, and you stroked your hair with a comb. In other words, you did muscular work on matter. This work produced electrical energy. The electrical energy, in turn, did work in generating a spark or in attracting and repelling bits of foil.

A similar series of events takes place when you play with a ball and bat. The bat and the ball have no ability to do work. The bat cannot hit the ball. You must swing the bat to hit the ball. You must do muscular work on the ball and the bat. The ball and bat now store energy and so have the ability to do work. (You are able to do this muscular work on the bat and ball because you have muscular energy. You obtain this energy from the food you eat.) When the bat hits the ball, its energy is used in doing the work of hitting the ball.

Mechanical energy, instead of electrical energy, is made by the work your muscles performed.

Producing Electrical Energy

How could you do work on matter to make, or generate, electrical energy? One simple way would be to reach into the atoms and yank out electrons. To remove an electron from an atom requires *work*. The force of attraction between the nucleus and the electron must be overcome, just as the elastic band on the slingshot had to be stretched.

Removing electrons from atoms is not as farfetched as it sounds. You actually did this when you stroked your hair with the comb. Since your hair contains carbon, we can again use a carbon atom as a model to show what happens.

The carbon atom has 6 electrons. If an electron is removed from a carbon atom, only 5 electrons are left. The carbon atom is no longer in a neutral condition, because the electric forces of its protons and electrons are not equal to each other.

Let's use mathematics again to prove this. We have in the atom —5 elementary charges, because we have only 5 electrons remaining. We have +6 elementary charges, because there are 6 protons in the nucleus. The sum of —5 and +6 is +1. There is an excess quantity of 1 positive elementary charge, which is free to exert an electric force outside the atom.

Since the carbon atom has the ability to exert an electric force, it has electrical energy. Electrical energy has been generated through work on matter that caused the removal of an electron.

If the wandering electron we talked about earlier came near the positively charged carbon atom, it would be attracted. Why? Would your hair, after being stroked by the comb, attract wandering electrons from the air? Why?

You also can place an excess charge on an atom by forcing an extra electron on it. In fact, you forced the electrons removed from the atoms of your hair onto the atoms in the comb. The comb gained the ability to exert an electric force: it attracted the bits of aluminum foil. Electrical energy was generated in the matter of the comb.

Can you figure out the excess charge on a carbon atom when an extra electron is forced onto it? What is the *sign* of the excess charge? What would happen to a wandering electron that came near such a carbon atom?

Whenever electrical energy is produced, matter has been worked on by something. Lightning bolts are the result of electrical energy generated by the work of violent air currents on water or ice particles. Whole cities are lighted by electrical energy generated by turbogenerators driven by the

How are the lightning bolts produced? How can houses be made safe from lightning?

work of falling water. In the five tests at the beginning of this unit, work from friction, from chemical action, from heat, from moving magnetic fields, and from light acted on matter to generate electrical energy.

In each of these examples electrical energy was generated through only one process! Electrons were added to or subtracted from neutral atoms of matter. The atoms gained excess charges of negative electricity or became positive by loss of electrons. The excess electrical charges enabled the matter to exert an electrical force.

Electrical Energy Generators

The action that takes place within the dry cell flashlight is an example of electrical energy being generated.

A dry cell is made up of a zinc sheet formed into a cup shape. The cup is filled with a chemical paste. Suspended in the paste is a carbon rod. Binding posts are attached to the cup and rod. Connections can be made to these posts so that the electrical energy generated by the dry cell can be drawn off and used.

The chemicals in the paste react with the zinc of the cup to do *chemical*

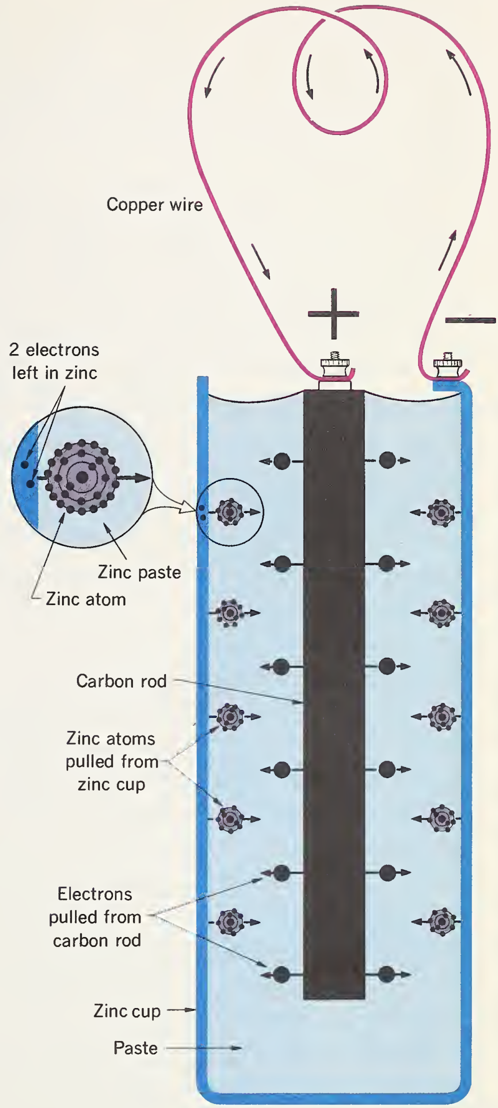
work. This chemical work consists of pulling billions of zinc atoms out of the cup. The zinc atom contains 30 electrons. How many protons does it contain?

As each zinc atom leaves the cup, 2 of its 30 electrons are left behind in the zinc sheet. As a result, the zinc sheet will contain more electrons than protons. The cup gains a *negative* electric charge. This negative charge can exert an electric force. The electric force can repel wandering electrons.

To show what happens, we connect a wire to the dry cell, as shown in the picture. (*A wire should never be left connected in this manner. It would ruin the dry cell.*) The wire provides a path along which electrons can travel. Electrons can move through this wire path much more easily than they can move through the air.

The billions of excess electrons in the zinc cup are *repelling* each other with an electric force. The copper wire provides an easy path through which some of them can get away from the cup and to the carbon rod.

The electrons move from the zinc cup, through the easy path of the wire, to the carbon rod. Work is being done in keeping these electrons moving. Electrical energy to do this work is generated by the chemical work being done inside the dry cell.



DRY CELL

The action we have traced—the changing of chemical energy into electrical energy—will continue until there is no longer any chemical energy available in the dry cell. The dry cell will then "go dead."

The cell that you built from a dime, moist paper, and a penny at the beginning of this unit, on page 99, worked in the same way as the dry cell. The chemical work performed by the salt solution in contact with the metals of the coins generated electrical energy. The dime acquired a positive charge and the penny acquired a negative charge. Electrons, forced through the wiring of the headphones, carried the electrical energy that produced the "click" you heard.

Conductors and Insulators

The wire connecting the binding posts of the dry cell provided a path through which electrons could easily move. Electrons were *conducted* from the zinc cup to the carbon rod. Any material through which electrons can easily flow is called a **conductor.** Any material through which electrons cannot flow easily is called an **insulator.**

Most metals—iron, zinc, aluminum, copper, silver, gold, platinum—are good conductors of moving electrons. Materials such as dry silk and cotton, hard rubber, ceramics, glass, plastics, wax, and even air are poor conductors, or insulators.

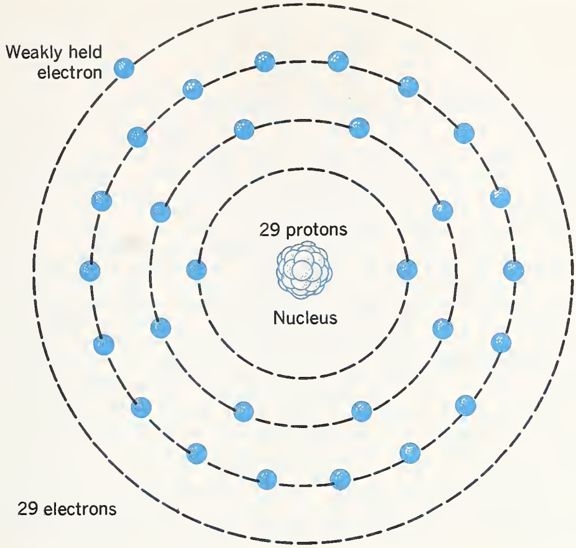
Why will some materials allow electrons to flow easily from one place to another, whereas others will not? Once again we must look into the behavior of atoms to find out.

Weakly Held Electrons

Copper is an excellent conductor of moving electrons. Much of the electrical wire used today is made of this element.

The atoms of copper, like the atoms of all matter, are constantly moving to and fro. They are said to be

The atoms of all matter are in constant motion. Although the vibrations may be small, they are vigorous. How is this motion detected?



COPPER ATOM

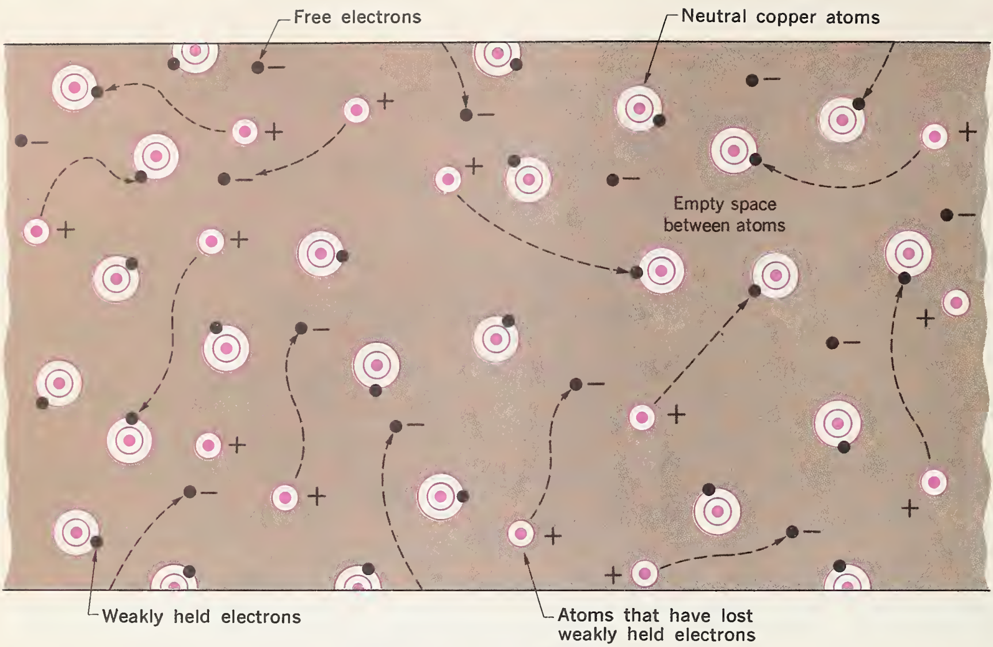
vibrating. The to-and-fro motions are extremely small but very vigorous. Materials that seem solid to us are alive with this motion. We detect the motion as *heat*.

Things that seem very cold to our touch—that have low temperatures—still contain heat. Their particles are vibrating rapidly.

The neutral copper atom contains 29 protons and 29 electrons. The arrangement of the electrons in the copper atom produces a special effect. *One electron is held very weakly in the atom*.

A copper wire is made up of billions and billions of atoms. Some of the atoms lose their weakly held electrons because of the vigorous atom vibration. The weakly held electrons are shaken loose and escape from their parent atoms. They become free. These free electrons will then wander through the empty space that is between the atoms in the wire.

But these electrons do not remain free for very long, nor do they travel very far. Other copper atoms, which have lost their original electrons, will quickly recapture them.



A SECTION OF COPPER WIRE

Notice that there are 13 atoms with a positive charge and 13 free electrons. The overall section of this wire is electrically neutral. How can you tell this?

When the weakly held electron escapes from the copper atom, only 28 electrons will be left. Since there are still 29 protons, the copper atom has a positive charge. It will attract free electrons. A free electron probably will be captured quickly by the charged atom, which will then again become a neutral atom and show no charge.

At any time, there will be many free electrons in the wire. It is because of these free electrons that copper and other metals are conductors.

Electron Flow in Conductors

What happens to free electrons when a dry cell is connected to the ends of the wire? We know that the negative post of the dry cell will push electrons into the wire, and electrons are pulled out at the positive post.

The free electrons are repelled by the negative electric force of the incoming electrons. Also, the free electrons are attracted by the positive electric force at the positive post of the dry cell. Under the influence of these forces, the

free electrons, during the time they are free, drift in the same direction, *away* from the *negative* post and *toward* the *positive* post of the dry cell.

As free electrons leave one end of the wire, space is made for electrons to move into the other end. The electrons from the dry cell, once inside the wire, are like free electrons. They hop from atom to atom, since they, too, are repelled by the electrons still coming in from the dry cell.

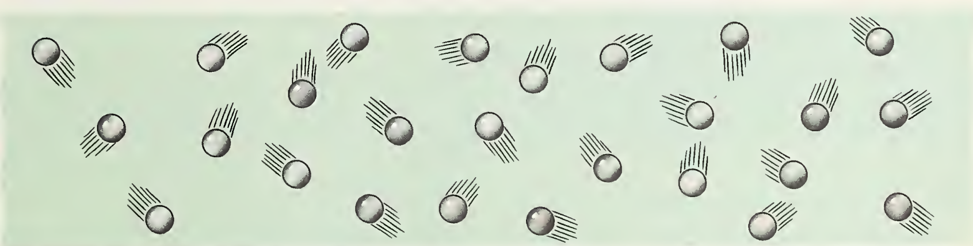
The effect is a continuous current of electrons flowing in *one* direction. Electrons in motion in one direction through a conductor are collectively called an *electric current.* Materials through which electric currents can freely flow are called good conductors.

Electron Flow in Insulators

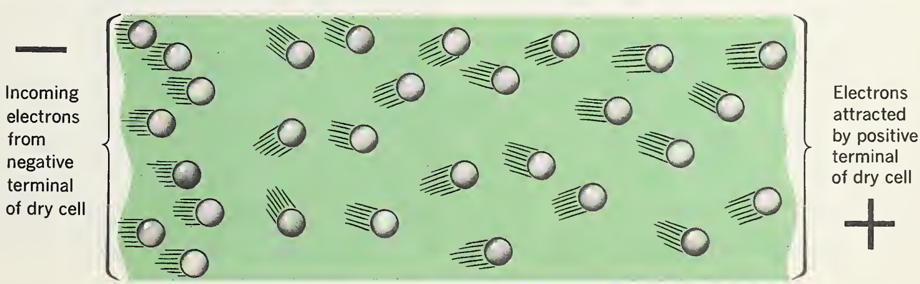
The behavior of electrons in insulators is very different from their behavior in conductors. Electrons do not become free and wander through the empty space between atoms. The atoms of matter making up insulators hold on to all their electrons. Violent vibrations will not shake electrons loose.

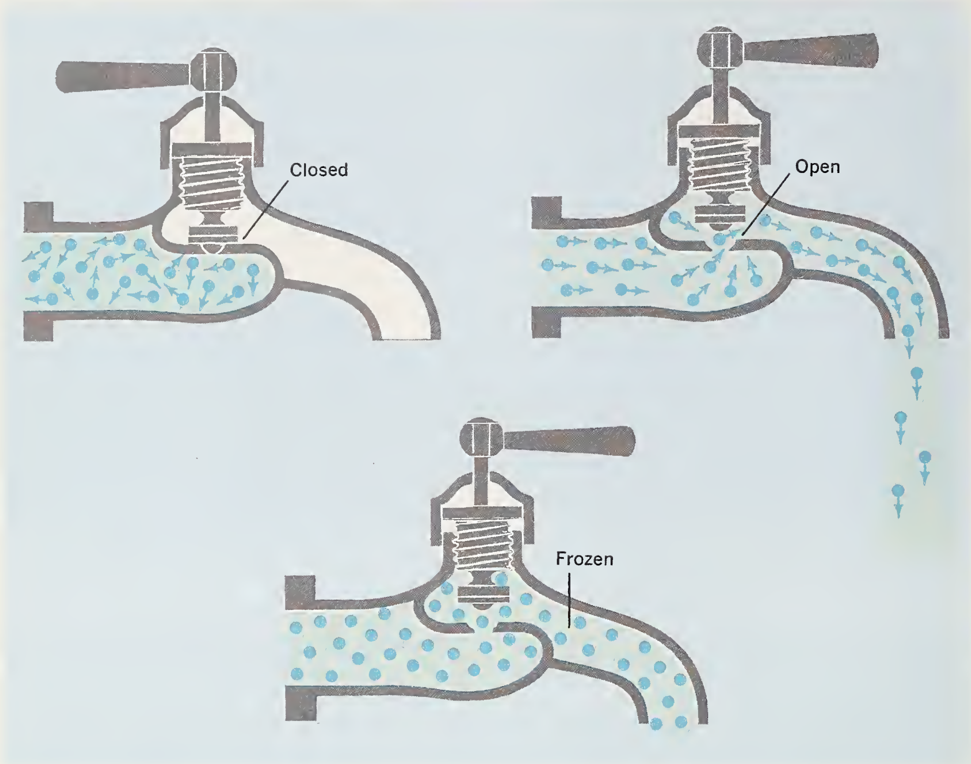
Since there would be no free electrons to move, there would be no current flow in a perfect insulator.

How would you describe the movement of free electrons?



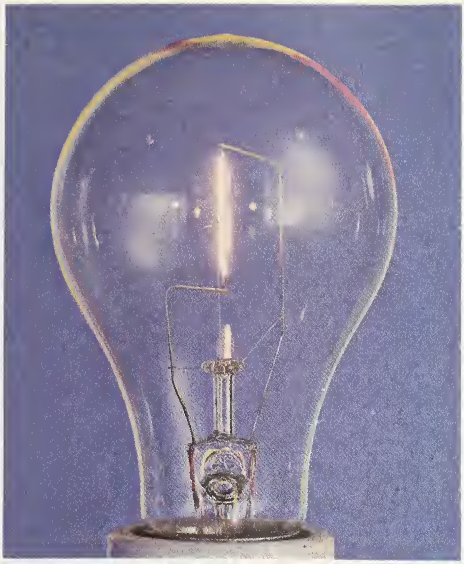
In what direction do free electrons drift when under the influence of electric forces?



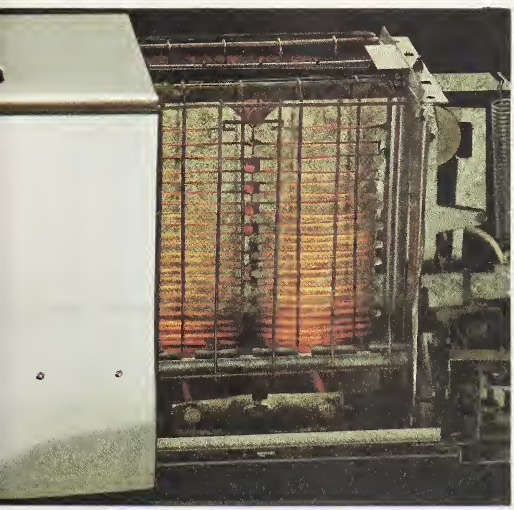


To understand better what happens in conductors and insulators, think of a pipe that is filled with water. The particles of water within the filled pipe may be compared to free electrons in a wire. These water particles are free to move under the influence of forces. If additional water particles are pushed into one end of the pipe, the whole column of water particles moves. Water particles immediately flow out of the other end of the pipe. A continuous flow of water particles through the pipe can be maintained. This action is like that in a conductor.

Now imagine that the water in the pipe freezes. The particles can no longer move freely. Additional particles of water cannot be forced into the pipe, nor can particles of water be withdrawn. This is something like what happens in an insulator.



Billions of electrons are flowing through the filaments of the light bulb and the toaster. What do you see happen when they flow through?



Heat and Electricity

The free electrons moved through conductors by electric forces do not really have open paths. Their trips, from the time they escape from a neutral atom to the time they are captured by a charged atom, are more like obstacle courses, or zig-zagging, winding paths.

Vibrating atoms keep bobbing up in the free electrons' paths, and collisions take place. These collisions between free electrons and atoms cause the atoms to vibrate more vigorously. Heat is produced. The vibration of particles of matter produces **thermal** (heat) **energy.**

As the number of electrons flowing through a conductor increases, the number of collisions increases. As the motion increases, the temperature of the material increases. The material may become "white hot" when a very large number of electrons flows. For example, about 5,000,000,000,000,000,000 electrons flow through the average electric light-bulb filament every second that it is turned on.

Electrical energy is transformed into heat energy by the action described. Light, which is another form of energy, is also generated in this action. But this is done through a more complicated process. You might be interested in finding out about this process.

Using What You Have Learned

Make a laboratory galvanometer. Use it to test as many as possible of the following:

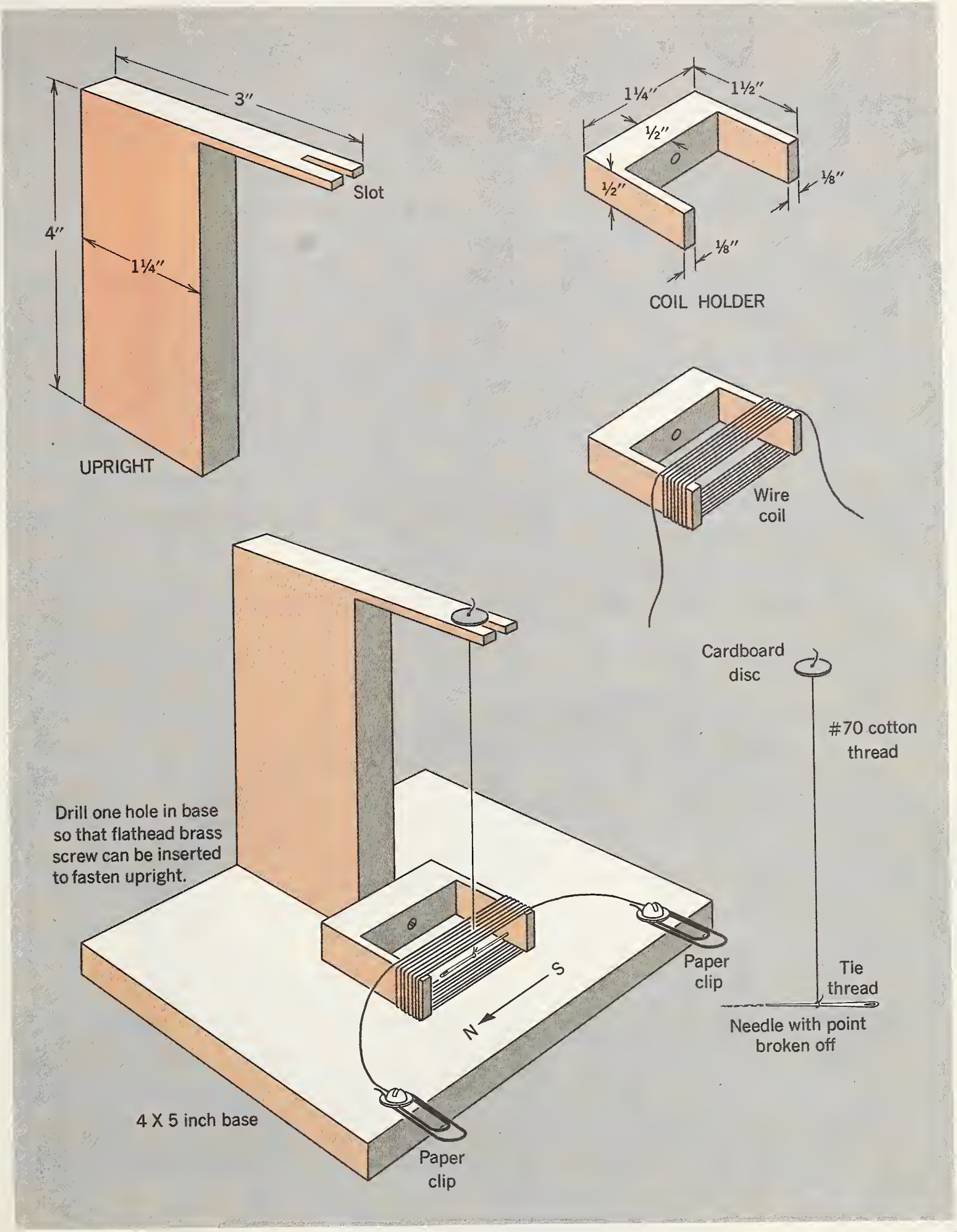
selenium photovoltaic cells
silicon solar cells
dime-penny cells
wire coil and bar magnet generators
other generators of electrical energy

To make the galvanometer, cut the upright, the coil holder, and the base from ordinary pine shelving to about the sizes shown. Drill holes in the base and the coil holder to take small *brass* screws. Fasten the upright to the base with one screw.

Wind the coil holder with 200 turns of #30 or #32 enameled wire. Do not pull the wire too tightly when winding, or the coil holder will be split. Leave the ends of the coil long enough to reach the paper-clip binding posts. Fasten the coil holder to the upright so that the coil clears the base by about one-quarter inch.

Mount the paper clips on the base with small brass roundhead screws and washers. Fasten the coil leads under the screwheads. Use fine sandpaper to remove the enamel from the wire ends so that electrical contact will be made.

Using pliers, break the point from a medium-sized sewing needle. Magnetize the needle by stroking it in one direction on one pole of a strong permanent magnet. Tie the needle to #70 cotton thread. Hang the thread from a cardboard disc. Adjust the thread so that the needle is balanced horizontally and hangs in the center of the coil. Turn the cardboard disc so that the needle is parallel with the coil. The coil should be positioned in a north-south direction, since the earth's magnetic field will influence the needle.


3″
Slot
4″
1¼″
UPRIGHT
1¼″
1½″
½″
½″
⅛″
⅛″
COIL HOLDER
Wire coil
Cardboard disc
#70 cotton thread
Drill one hole in base so that flathead brass screw can be inserted to fasten upright.
S
N
Paper clip
Tie thread
Needle with point broken off
4 X 5 inch base
Paper clip

Electricity and Magnetism

In the third of the five tests you did at the beginning of the unit, you placed a wire over a magnetic compass. When an electric current (a flow of electrons) passed through the wire, an effect was seen: the needle of the magnetic compass moved. What caused this movement?

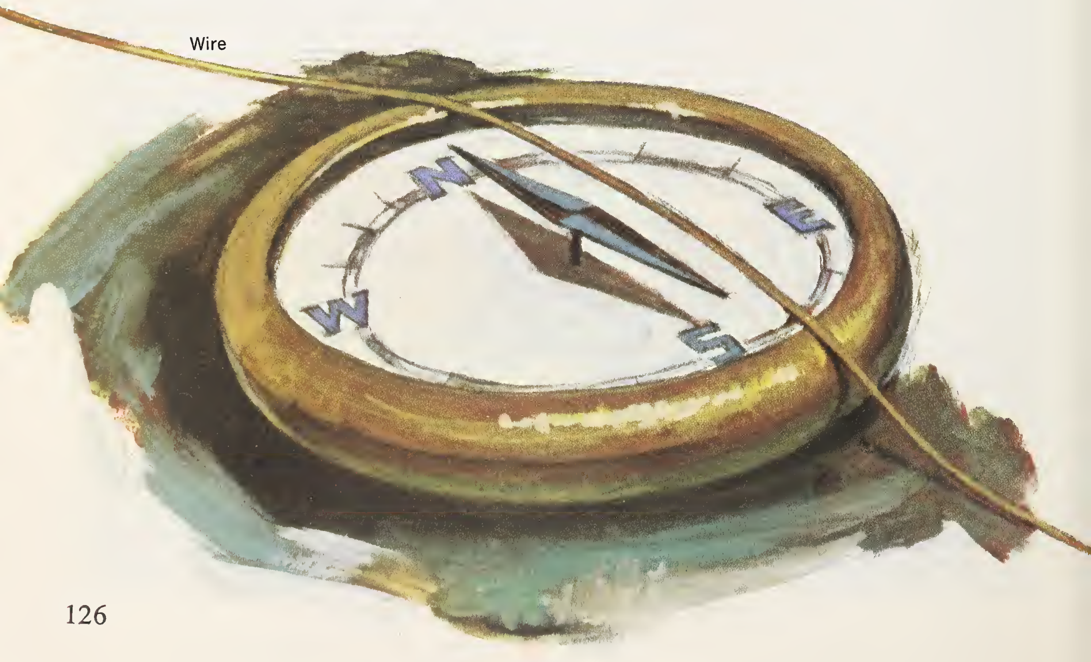
Force must be exerted on a compass needle to make it move. Since the needle is made of a magnetic material, steel, it will react to magnetic force. The current flowing through the wire must have produced the magnetic force to move the needle.

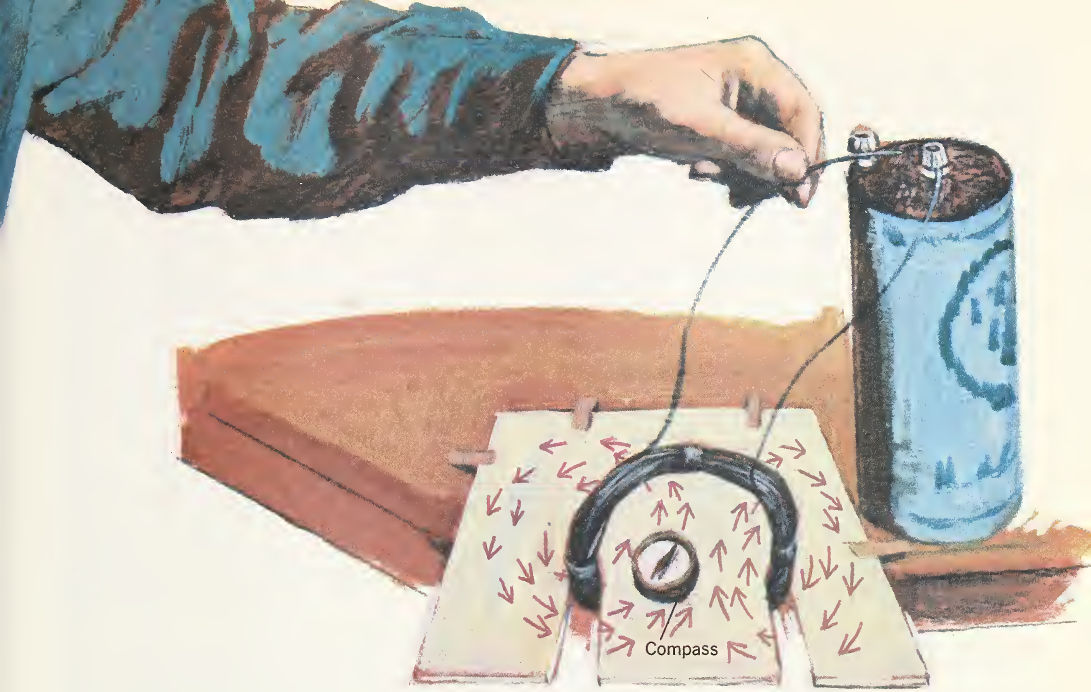
A flow of electrons produces the effect of magnetism.

Just how moving electrons produce a magnetic force is not yet fully understood by scientists. However, you can investigate the magnetic effects of a flow of electrons through a wire.

Wind a 6-inch-diameter coil of about 30 turns of bell wire. Cut a piece of cardboard as on the right. Place the coil in the cardboard slots and tape

What happens to the needle of the compass when current flows through the wire?





How is a magnetic field produced? What happens when the current is turned off?

the whole assembly to the corner of a wooden table. After placing a small compass on the cardboard, connect the coil to a dry cell for just a second. Note the direction the compass needle points while current is flowing in the coil. Break the circuit immediately after looking at the compass.

Remove the compass. Then draw the exact position of the compass needle on the cardboard. Repeat this procedure a number of times, placing the compass on different spots on the cardboard.

You will have drawn many arrows. These arrows show the **magnetic field** about the wires of the coil. A field is a region or space in which some activity takes place. A magnetic field is a space in which a magnetic force is experienced.

The magnetic field around the coil of wire has a definite shape and direction. Any substance that can be magnetized, such as iron filings, will be subject to a magnetic force in this field. The field exists only as long as current is flowing—that is, electrons

are moving in the same direction—in the wire. When the electric current in the wire is made to stop flowing, the magnetic field ceases to exist.

Now get a permanent bar magnet and place it on a piece of paper. Explore the magnetic field about the bar magnet with a small compass as you did before. Again draw arrows that indicate the positions of the compass needle.

The field of the permanent magnet also has a definite shape and direction. It resembles the magnetic field of the current-carrying coil.

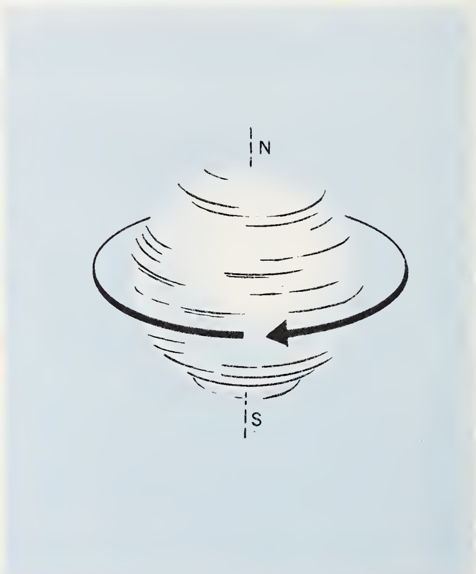
Permanent Magnets

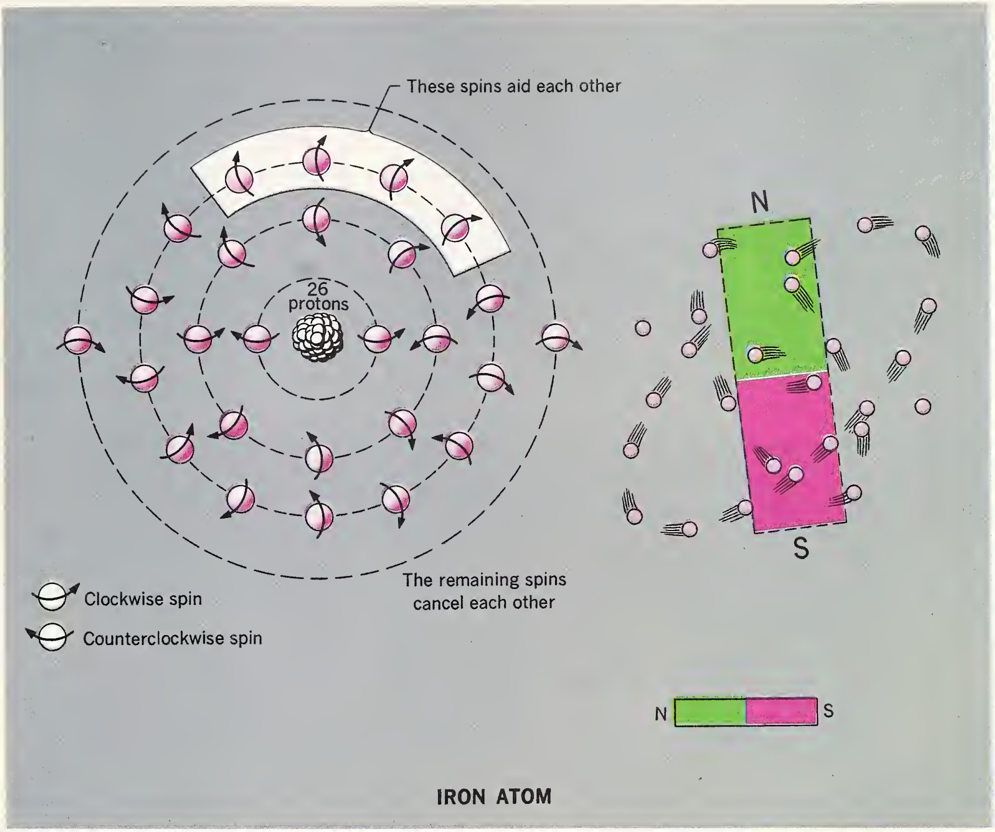
If a current of moving electrons, or electricity in motion, generates a magnetic force, what makes a permanent magnet? Strange as it may seem, the magnetism of a permanent magnet also is generated by the electricity of moving electrons.

You have learned that in the atom, the electrons not only revolve about the nucleus but also rotate on their own axes. In a great many materials, the rotations of the electrons are in directions that cancel each other. In certain other elements, such as nickel and

What does the compass indicate about the field?

A spinning electron generates magnetic force.





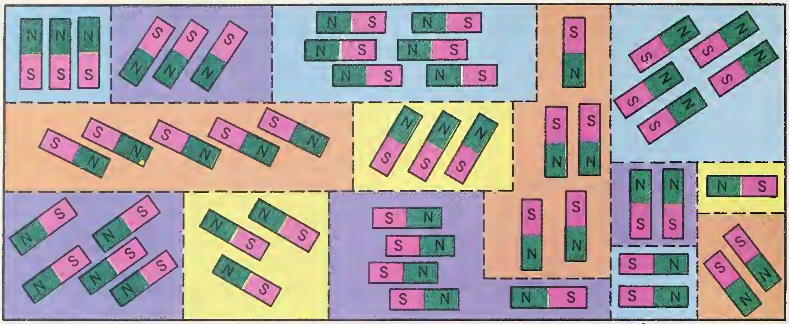
The bar magnet on the right serves as magnetic model for the iron atom.

iron, the spins of some of the electrons aid each other to produce the effect of moving electricity. This moving electricity generates a magnetic force.

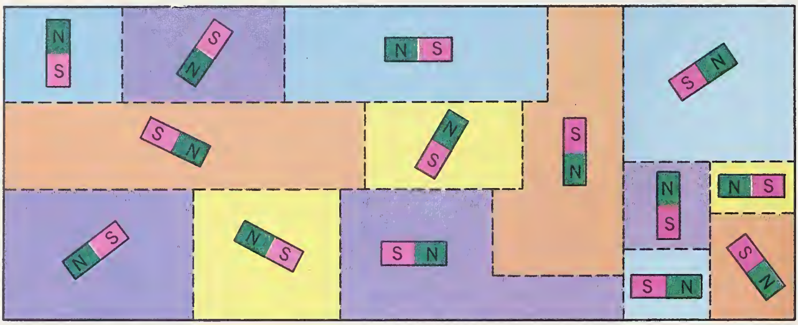
Each atom in a piece of iron or nickel is, for the above reason, a tiny magnet. We could think of a small bar magnet as being the magnetic model of, for example, the iron atom.

This tiny bar magnet would be surrounded by the same kind of magnetic field you traced for the large bar magnet.

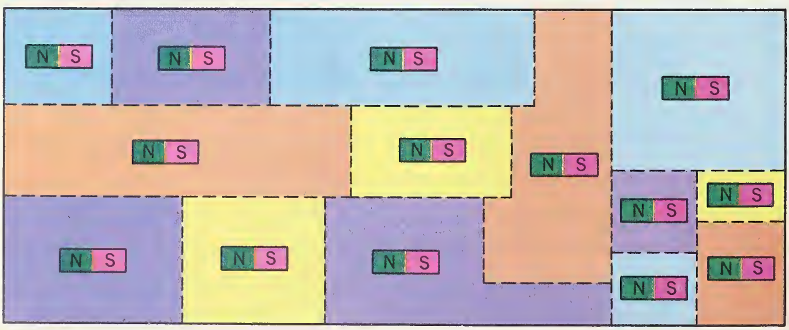
But iron does not normally exert a magnetic force. You know that paper clips that are made of iron do not attract or repel each other. How can this be explained?



Atoms magnetically arrange themselves in small groups.



Each group is now shown as a single bar magnet.



Under the force of a magnetic field, atoms arrange themselves into one magnetic group.

The answer is quite simple. The magnetic fields of the atoms cancel each other. The atoms in a piece of iron arrange themselves in small groups. Within each group the magnetic poles of the atoms all point in the same direction. A model of this group arrangement is shown in the first picture on the left.

Since the magnetic poles in each group point in the same direction, the magnetic fields of the atoms aid each other. For this reason, each group can be pictured as a single bar magnet.

The groups are shown in the second picture as single bar magnets. But the poles of the single bar magnets point in various directions. Because of this, iron normally does not exert a magnetic force.

Suppose that an iron paper clip is brought near a permanent magnet. The strong magnetic field of the permanent magnet will rearrange the iron atoms as shown in the third picture. More of the atoms in the clip will magnetically point in the same direction. Their magnetic fields will aid each other. The clip, magnetized, now exerts a magnetic force. It is attracted to the permanent magnet.

To show that the atoms in iron must magnetically point in the same direction to exert a magnetic force, try this test. Hang a paper clip from a bar magnet. Heat the clip by means of a candle until it is very hot. The clip will fall from the magnet. Why?

When heat energy is added to matter, its atoms move much more rapidly. Because of this, the atoms will be so jarred that they will all point in different directions. Their magnetic fields will cancel each other. The heated iron will *not* show a magnetic effect.

Some permanent magnets are made of very hard steel. The atoms in steel are strongly held in position. Permanent magnets stay magnetized for a long time. All their atoms remain pointed in the same direction. They can be **demagnetized**—lose their magnetism—by being dropped. Sudden jars or great heat will rearrange the atoms.

Iron like that in paper clips is a soft metal. Its atoms are not strongly held in position. Because of atom vibrations, its atoms become magnetically mixed up even at low temperatures. Soft iron that has been magnetized will not hold its magnetism for very long.

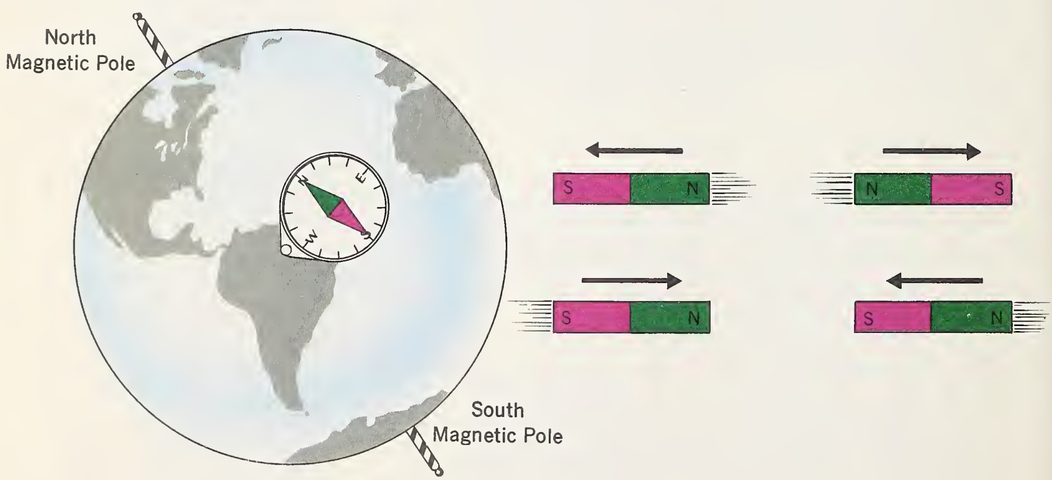
Magnetic Poles

You have used the phrase *magnetic poles* many times. You know that a magnet has two poles, a north pole and a south pole. The poles seem to be the centers of magnetic force. Can you tell how the poles got the names *north* and *south?*

A compass needle is a small magnet. When left alone, one end of the needle will tend to seek the North Magnetic Pole of the earth. For this reason, this end of the needle is called the *north-seeking pole,* or, for short, the north pole. Of course, the other end would be called the *south-seeking pole,* or the south pole.

In handling magnets, you cannot help noticing that like poles repel and unlike poles attract each other. In this respect, they are much like electric charges. But magnetism is a different property of matter from electricity. It is a property of electricity in motion.

Like magnetic poles repel each other. Unlike magnetic poles attract each other.



In the near future, every home may have a television viewer connected to the telephone, which will enable the speakers to see each other. On the right is a tape recorder, which magnetically records sounds on a tape that can be played many times and then erased and used to make other recordings.

Putting Electrons to Work

You now know that gases, liquids, and solids are states of matter.

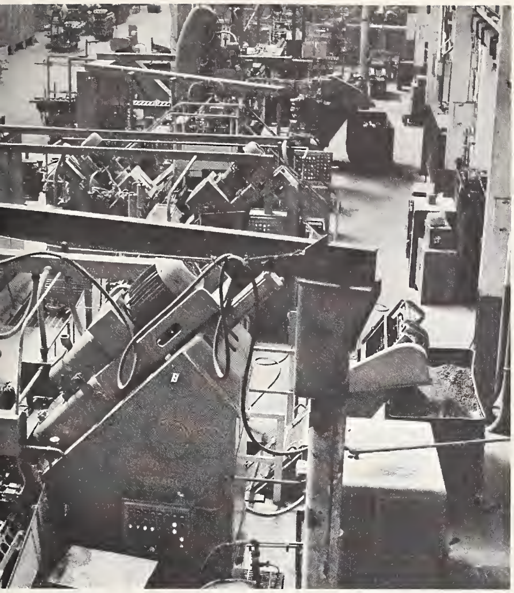
You have learned that matter is defined by its properties—mass, electricity, and magnetism. The mass of matter is the center of its gravitational force.. All matter can be broken down into elementary particles—neutrons, protons, and electrons. You also know that these particles are the centers of electrical and nuclear forces. You have learned many of the effects of these forces. Can you tell how scientists put these forces to work?

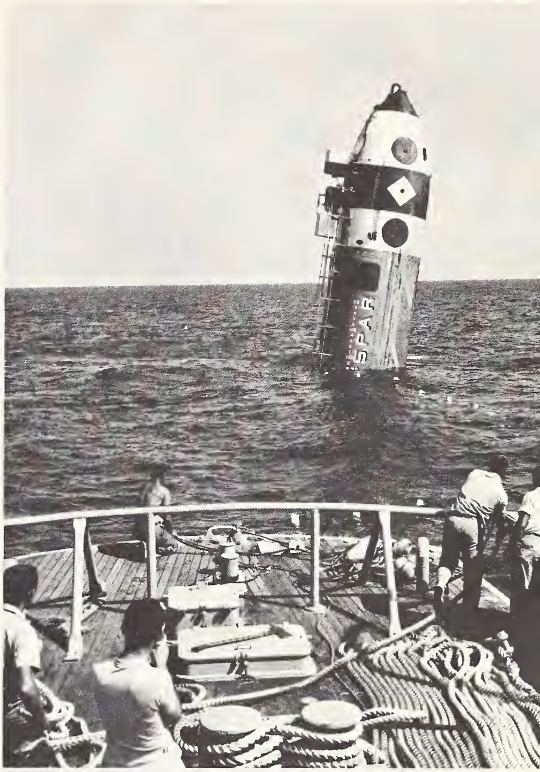
In the twentieth century the science of electronics has given rise to many discoveries, some of which led to the invention of radio, television, electric eyes, radar, tape recording, and, more recently, computers and automated machinery.

Computers

Electronics makes possible "memory systems" that can store large amounts of information very quickly. These memory systems are used to do an amazing variety of things.

In a computer, a magnetic tape holds information and supplies it on demand at a speed far greater than that of human calculation. For example, a computer can solve in an hour mathematical problems that it would take a skilled mathematician a lifetime to solve. The machines take over tiresome calculations and so relieve men to do more creative work. Electronic computers are now used to control other kinds of machines, to keep bank and payroll records, to store and produce inventory information on demand, to determine the probabilities on which insurance rates are based, and to perform many other tasks. This is why computers have been called "thinking machines."





Here you see two examples of automation. Above left, a factory assembly line is automatically controlled. On the right, a specially built ocean vessel is flipped on its end from a control ship. Once on end, it will be boarded by scientists who will conduct research projects from it.

Automation

Automation replaces the human worker with a machine that can do his job faster and more accurately. The machine is able to "see" errors and correct them. The machines become inspectors as well as workers.

The automatic washer is an example of a low degree of automation. It is loaded and turned on. It operates until it turns itself off. Computers show a high degree. They control and receive information from other machines and correct errors.

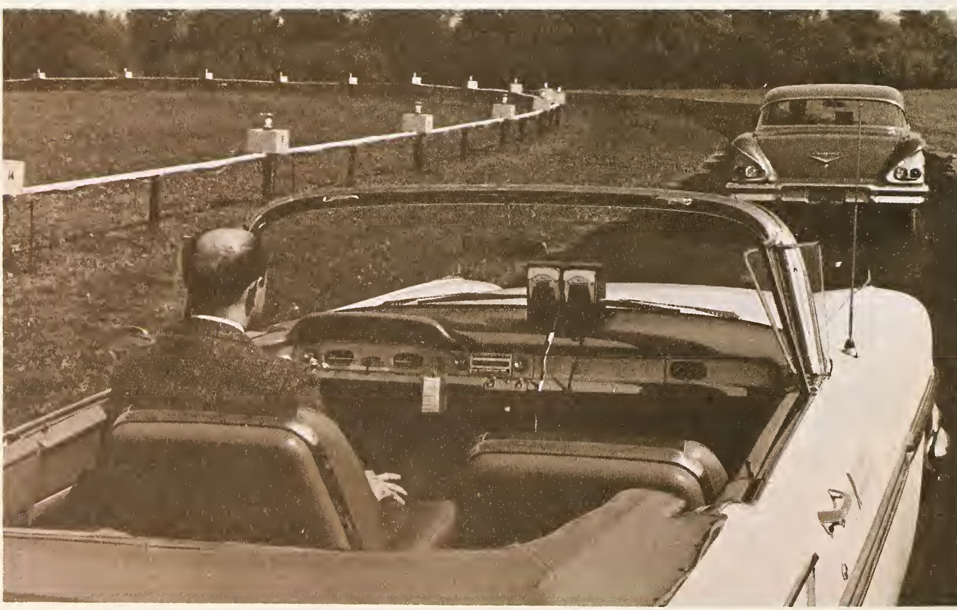
Automation with electronic controls can be utilized in almost every factory or process. Metal parts can be guided through hundreds of operations without a human touching them. Electronically guided tools can cut, drill, and weld. Automatic controls can adjust temperature, pressure, and oil flow.

The Future for Electronics

The number of ways in which electrons will be put to use in the future appears limitless. For example, electronics may be used one day to make highways automatic. Experiments have already shown that electronic devices can guide and control automobiles and prevent accidents. As scientists experiment in their laboratories, new kinds of electronic instruments are developed. These instruments lead to new discoveries about the laws of nature. These discoveries lead to new kinds of industry that branch out into new, more effective methods of communication, safer and faster travel, less expensive products through automated mass production, speedier ways to solve complex mathematical problems, and better ways to control and prevent human problems.

You now know a little bit about the science of electronics. The uses to which scientists put electrons are many. The science of electronics is vital to the exploration of outer space, to national defense, to education, to medicine, and to communications. If you choose a career in electronics, you will be working with the most powerful forces of nature—electricity, magnetism, and the mysterious force that holds together the parts of an atomic nucleus.

In your lifetime, automated highways may come into use. Once you enter such a highway, electrical controls take over and guide your car. What are the advantages of such a system?



Using What You Have Learned

1. Make a list of the ways in which gravitational force is put to work. A pile driver in which a heavy weight is dropped is one way.

2. Invite someone from your local telephone company to come talk about satellites and solar batteries. You might suggest that the speaker discuss other uses for solar batteries, such as how solar batteries can be of value to people in remote areas and whether solar batteries will someday replace present-day fuels as sources of energy.

3. Try making up small cells using various combinations of metals and chemicals. Try iron (nails or washers), copper, lead, zinc (galvanized washers or nails), tin (from tin-coated cans), aluminum (kitchen foil), and other available metals. Use salt water, vinegar, lemon juice, household bleach, and other liquids that are safe to handle. Determine which combinations will generate electrical energy by testing with your homemade galvanometer. Try to find out which are the negative and the positive terminals of the successful cells.

4. Get an unmarked bar magnet and a compass. How would you identify the poles of the unmarked magnet?

5. Read about Henri Becquerel, Ernest Rutherford, or Niels Bohr and write a report on his contribution to our knowledge of atoms, protons, and electrons.

6. Try this interesting puzzle. Get two of the same kind of large sewing needles. Magnetize only one as described in the activity on page 124. Now have someone mix up the two needles so that you cannot tell which one you magnetized. Using only the two needles, plan a test for telling which one is magnetized.

WHAT YOU KNOW ABOUT

Electricity and Electronics

What You Have Learned

The science of electronics studies the behavior of **electrons** and the forces of electricity and magnetism.

Electricity is present in the atoms of all matter. Every atom consists of a nucleus, made up of **protons** and **neutrons,** and electrons that revolve around the nucleus. Protons, neutrons, and electrons are called **elementary particles,** because it is believed that they cannot be further divided. The positive electrical **charge** of the proton and the negative electrical charge of the electron are called **elementary charges.** The neutron has no electrical charge, although it has **gravitational mass.** Unlike charges attract each other; like charges repel each other.

An atom that contains the same number of protons and electrons is **neutral.** For an atom to become electrically charged, electrons must be added or taken away, upsetting the balance between the positive and negative charges. The strong tendency of electrons to move away from the nucleus is called **inertia.**

Electricity is the movement of electrons through a **conductor.** A conductor is a substance through which electrons can pass easily. A substance through which electrons cannot pass easily is called an **insulator.**

The flow of electrons through a conductor produces the effect of magnetism around the conductor. The space in which this magnetic effect can be experienced is called a **magnetic field.**

Electricity, magnetism, and the force that holds together the nucleus of the atom are the most powerful forces in nature.

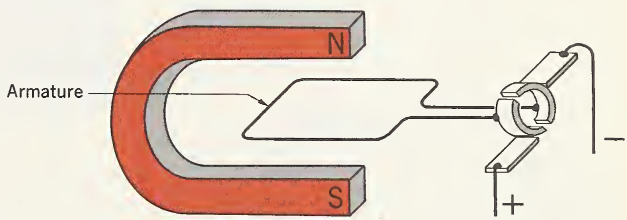
Checklist of Science Words

Here are some science words you read about in this unit. Can you tell what you have learned about each one?

accelerators	galvanometer	neutrons
conductor	gravitational mass	photoelectric
demagnetized	inertia	protons
elementary charges	insulator	thermal energy

How Does a Motor Run?

From what you know about electricity, can you tell what happens when an electric current is sent through the wire? Trace this diagram in your notebook and then draw arrows to show the flow of electricity and the direction of movement of the rotating coil (armature).



Complete the Sentence

Write the numbers 1 to 7 in your notebook. Next to each number write the answer that best completes the sentence.

1. An atom consists of a ___?___ and one or more ___?___.
2. The nucleus of an atom contains ___?___ and ___?___.
3. A proton has a ___?___ charge of electricity.
4. Unlike charges ___?___ each other.
5. An electric current is the flow of free electrons through a ___?___.
6. A battery changes ___?___ energy into electrical energy.
7. The flow of electricity through a conductor produces a ___?___ effect.

YOU CAN LEARN MORE ABOUT

Electricity and Electronics

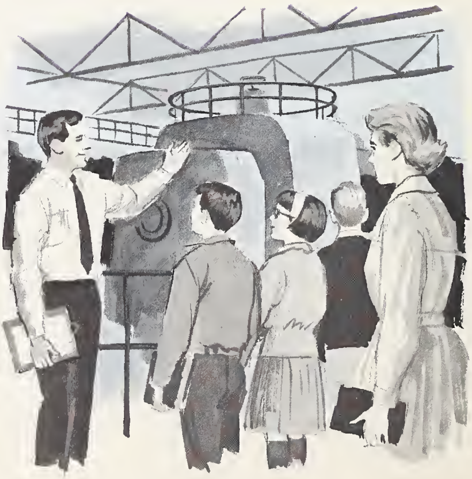
You Can Make an Electroscope

An electroscope detects charges of electricity. To make one you will need a tall jar such as a jelly jar, copper or brass wire, pieces of aluminum foil, and a waxed cork or insulating wax.

Push an L-shaped piece of copper or brass wire through the cork or wax. Hang a string of aluminum foil from the lower end of the wire. Place the cork in the bottle. The cork or wax will prevent any charge from leaking away.

Now bring a charged object, such as a comb that you have run through your hair, near the bottle. What happens to the strip of foil? Can you tell whether the charge is like or unlike that of the strip?

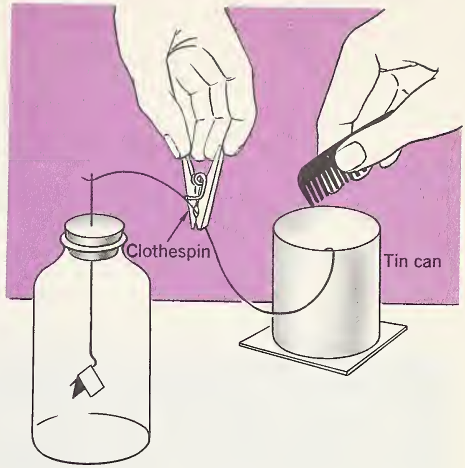
You Can Visit



Your local electric utility company may have guided tours of their plants. At these plants you will see how electricity is produced. Ask the tour guide how atomic energy may be used to produce electricity. Would this be a more or less expensive operation than the way electricity is currently produced?

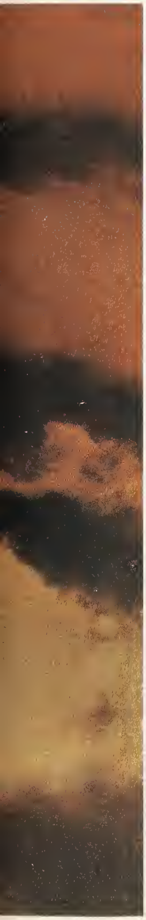
You Can Use Your Electroscope

By using your electroscope you can see that electricity flows through a conductor. Fasten the end of a wire to a can. Hold the other end of the wire to the electroscope you made. Charge the can by rubbing a plastic comb with fur and then touching the can. What happens to the aluminum foil? How does this show that electricity flows in a conductor?



You Can Read

1. *Electronics for Young People,* by Jeanne Bendick. Information about electronics and its applications.
2. *Wonder Worker: The Story of Electricity,* by Walter Buehr. Examples of electricity at work and the work of early scientists with electricity.
3. *The Bright Design,* by Katherine B. Shippen. The history of electrical energy.
4. *Electricity: The Story of Power,* by Arnold Mandelbaum. A history of electrical discovery and invention.
5. *Electrical Genius: Nicola Tesla,* by Arthur J. Beckhard. The story of the inventor of the alternating-current motor, the telephone amplifier, and other devices.

5

Astronomy

Models of the Solar System

Locating Things in Space

Finding the Sizes of Objects in Space

Viewing the Universe

Objects in the sky always have fascinated man—from earliest times to the present. The stars, moon, sun, and planets have been studied by careful observers for thousands of years. In this unit, you will discover some of the methods astronomers use to answer questions about objects millions of miles away.

Models of the Solar System

To study the structure of an insect, you can catch a fly or a beetle and observe it carefully with a magnifying glass. To learn about its behavior, you can do many things to it. You can put it in a cold place, turn it upside down, or shine a light on it.

You can learn about many objects on earth—insects, flowers, magnets, tuning forks—by examining them closely or experimenting with them, but it is not possible to learn about the stars and planets this way. These objects can only be observed from great distances.

How do these pictures show the direction the sun seems to move across the sky?

Some observations of stars and planets are quite simple and were made thousands of years ago. Every clear morning, the sun may be seen in the eastern sky. It appears to move slowly toward the west, where it sets in the evening. Each day the movement is repeated. On some clear evenings you can see the moon in the eastern sky. In what direction does it appear to move across the sky? How long does it take? In what direction do the stars appear to move across the sky? How long do they take to move? How can you explain these motions?

To explain the motions of the sun, moon, and stars, you must have ideas about where each is located in space. You must also have ideas about their movements in space. Since the moon, sun, and stars are so far from the earth, it is impossible to get these ideas by observing their positions and movements directly. You have to imagine where they are located in space and how they move. When you have a set of such ideas, you have a *model*. Over the years astronomers have developed several different models to show relationships among the sun, moon, and planets.

As each model has been developed, it has been used to answer such questions as: Why do these bodies appear to move from east to west across the sky? Why do planets appear brighter at some times than at others? What causes the seasons?

Models may take different forms. At first a model may be ideas carried around in the head of its inventor. Later he may describe his model by writing about it. He may draw a diagram to show what it is like. He may actually construct the model to demonstrate how his ideas can be used in giving an explanation.

Making Models to Explain Ideas

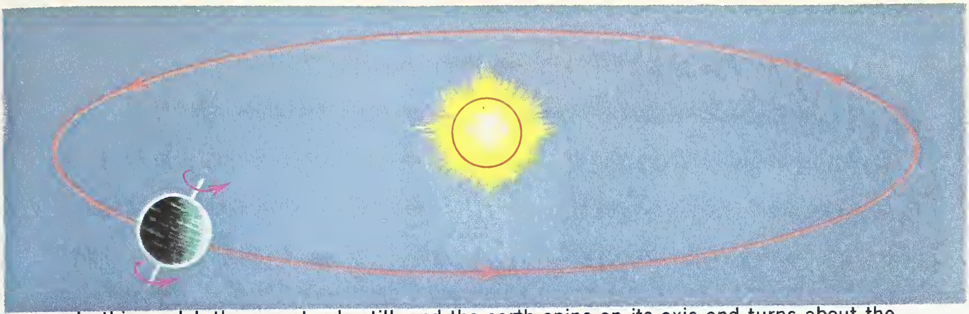
You probably have made models of the planets to show their relative sizes. You also may have hung them from the ceiling of your classroom to show their arrangement around the sun. You made these models after studying a number of modern ideas about the planets. The ideas about the sun and its planets that we accept today have been developed only within the last four hundred years. Four hundred years is a short time compared with the many thousands of years that human beings have been on the earth.

Make a list of the things that you on the earth can observe about the sun, moon, and stars. Be sure that your list includes only what you actually can observe. Include items that you will be able to observe over a one-year period.

Suppose this were all that you knew about the sun, moon, and stars. In other words, suppose you lived several thousand years ago. How would you explain the things you observed? Think up ideas that would help you explain them. What kind of model can you construct? Where will you put the sun in your model? Where will you put the earth and the moon? Is it possible to think of more than one model?

On the top of the next page you can see a model that can be used to explain a number of events. The sun does not move in this model. The earth spins on an axis. It makes one complete turn every twenty-four hours. Use a globe or a ball to explain how this model accounts for the rising of the sun, its apparent movement across the sky, its setting about twelve hours after rising, and its rising again the next morning.

Now make a model in which the earth stands still. Use it to explain sunrise, the movement of the sun across the sky, sunset, and another sunrise. Does your new model account for the same observed facts as the first model? How does it?



In this model, the sun stands still, and the earth spins on its axis and turns about the sun every 24 hours. How does this model account for the rising and setting of the sun?

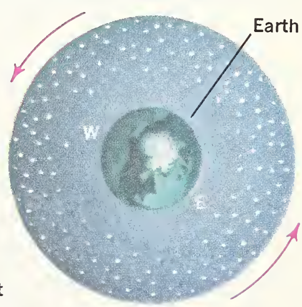
Which model gives the better explanation? Neither one! For the observations that you set out to explain (sunrise, sunset, sunrise again), both models are "right." Both can be used to explain what you see. In fact, both of these models have been used. Why do we accept the one we do today?

What evidence obtained by actual observation can be used to prove that the earth rotates?

An Earth-Centered Model

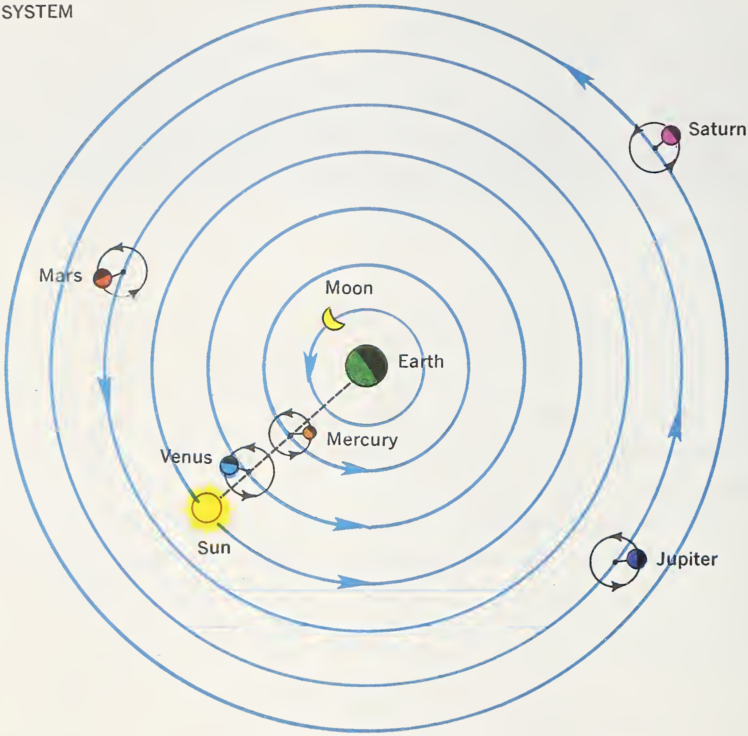
When you look up at the stars at night, you feel as though you are at the center of all you observe. It was reasonable for early astronomers to think of a model in which the earth was the center of everything. You cannot detect any movement of the earth. It seems to be motionless. Therefore, a description of a motionless earth at the center of everything seemed to be quite proper.

To complete this model, early astronomers imagined the earth to be surrounded by an enormous shell or sphere. The stars were set within this sphere. The sphere made one complete turn around the earth every twenty-four hours. This reasoning accounted for the apparent daily movement of the stars across the sky from east to west.



In this model, a sphere of fixed stars revolves every 24 hours about a motionless earth.

PTOLEMAIC SYSTEM



The diagram above shows one such earth-centered model. This is called the **Ptolemaic** (tol-uh-MAY-ik) model. It was invented by Claudius Ptolemy (TOL-uh-mee) about eighteen hundred years ago to explain the movements of the sun, moon, and planets around the earth. In this model, the moon revolved around the earth once in about twenty-five hours. The sun and stars made the trip in twenty-four hours. Why did the moon seem to move more slowly than the sun and the stars?

However, the planets presented a problem. Their motion was not the same as that of the stars. Although the planets revolved around the earth along with the stars every day, they did not always appear in exactly the same positions among the stars.

The diagram above shows how one of the planets, Mars, may shift its position among the stars over a period of nine months.

You will see that on June 1, Mars was near the stars in Group A. By July 1, its position had shifted eastward so that it was near the stars in Group B. By August 1 it had moved a little beyond this group of stars, and by September 1 it had moved even farther eastward.

But look what happened between September 1 and October 1. The position of Mars shifted *backward* toward the west. Then, between October 1 and November 1, it shifted again toward the east. Finally, between November 1 and February 1, it shifted eastward from a position near the stars in Group

B to those in Group D. It was because these bodies shift their positions among the stars that they were called *planets*. The word *planets* means "wandering." The backward shift in position of a planet is called **retrograde motion** (RET-ruh-grayd).

The Ptolemaic model had to explain two things about the observed motion of planets. First, it had to explain why they moved eastward among the stars. This could be done by having them revolve around the earth a little more slowly than the stars revolved. Second, the model had to explain retrograde motion.

As you can see in the diagram on page 148, Ptolemy had the idea that

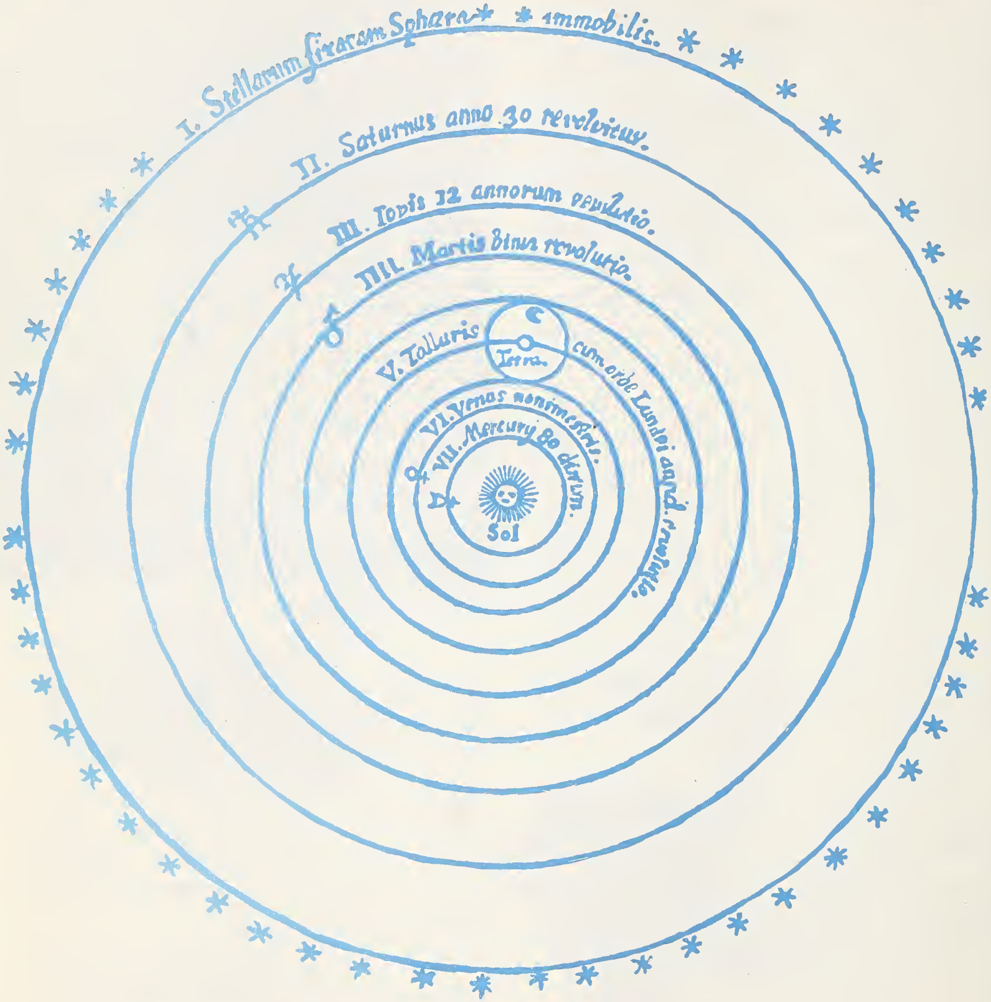
each planet went around the earth in two circles. One was the large circle that carried it completely around the sun. The other was a smaller circle, the center of which was on the larger circle. The small circle was called an **epicycle** (EP-uh-sy-k'l). As Mars revolves around the center of the smaller circle it would appear to be going backward at times. You can demonstrate this to yourself in the following manner. Stretch out your arm and hold a pencil in your hand as the boy in the picture on page 150 is doing. As you turn around move the pencil in circles. You will see that the pencil seems to be forming loops as you turn around. You will also see that at times the pencil appears to be moving in the same direction you are. At other times it appears to be moving backward. It was in a way like this that Ptolemy used his model to explain retrograde motion of planets.

There was another fact about Mars that astronomers had observed. At the times when Mars was retrograding (moving backward), it appeared to be brightest. How can the Ptolemaic model be used to explain this interesting fact about Mars?

Ptolemy was able to build a model of the universe that fit all the facts known in his lifetime. His model seems complicated today, but it was a great achievement. Ptolemy's model, with the earth perfectly still and at the center of the universe, accounted for everything that could be seen with the unaided eye. This model was widely accepted for about fifteen hundred years. No one really challenged it until the sixteenth century.

Claudius Ptolemy was a Greek astronomer.

The Ptolemaic model of the universe also may be called the Ptolemaic theory. You remember that *theories* are sets of ideas that explain how or why things happen as they do. How are models different from theories?

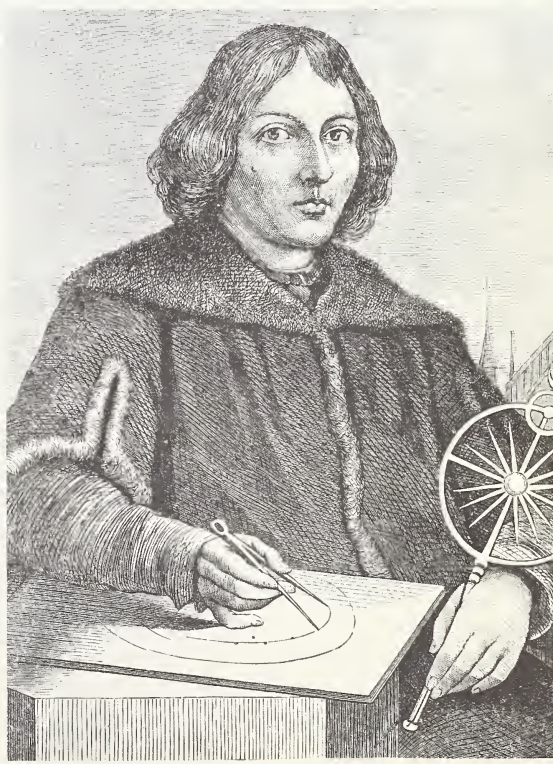


THE WORLD OF COPERNICUS

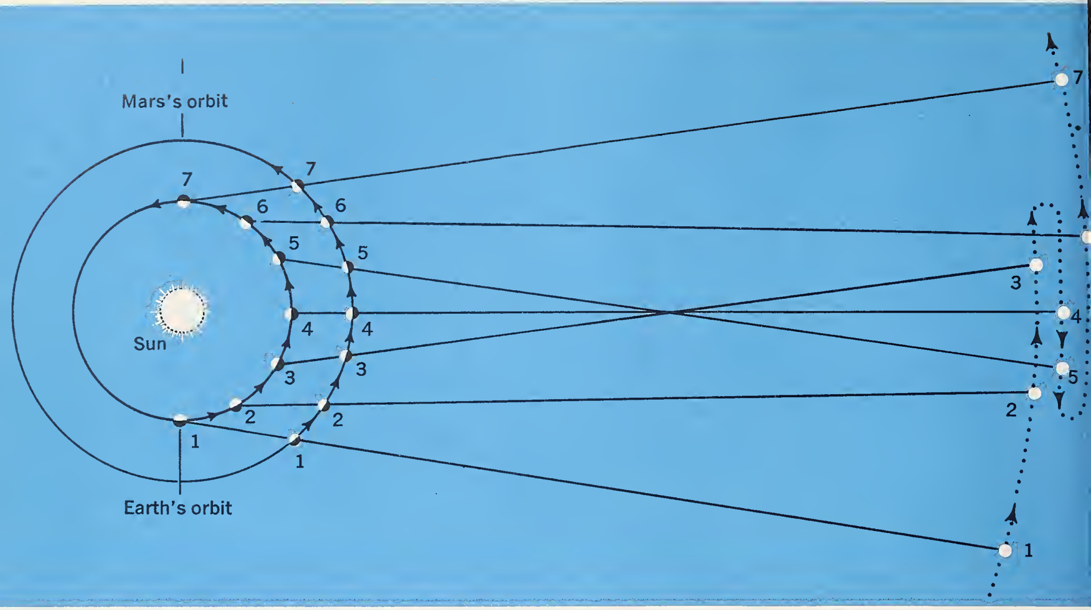
A Sun-Centered Model

In 1543, Nicolaus Copernicus published a book in which he suggested that the sun, not the earth, was at the center of the solar system. Copernicus was not the first to hold this view. In fact, some scientists who lived before Ptolemy thought the sun was at the center. But Copernicus' theory came after a very long period in which most people considered the earth to be at the center of everything. Copernicus looked at the universe in a new and bold way for his time.

How is a new theory tested? First, Copernicus had to show that his theory accounted for the same facts as did Ptolemy's. And, indeed, you can explain day and night without moving the sun around the earth each day: you can spin the earth instead. But what about the motion of planets? What about the motion of Mars? You have seen how Ptolemy's circles accounted for the fact that Mars seemed to retrograde and to get brighter at times. Can you use Copernicus' model to explain these two facts?



Nicolaus Copernicus, a sixteenth-century astronomer, overthrew the age-old belief that the earth was fixed at the center of the universe. He formed the general plan of the solar system which today's scientists accept. On the left, you see a drawing of Copernicus' idea of the universe. Can you describe it?



Retrograde Explained by Copernicus' Model

In the diagram, you see the orbits of earth and Mars around the sun as Copernicus thought of them. The numbers on the earth's orbit show the positions of the earth at different times, one month apart. (Similarly, the numbers on Mars's orbit show the positions of that planet on the same days.) Now look at the line connecting point 1 on the earth's orbit with point 1 on Mars's orbit. This line is extended out to the stars. It shows where Mars would be seen against the background of stars by an observer on earth.

Look at the points numbered 2 on both orbits. The line through these points shows where Mars is seen from the earth one month later. After still another month, Mars is seen along the line through points 3. During this three-month period, Mars seems to move across the sky from west to east. Notice that the point where Mars seems to be depends on *both* the position of the earth *and* the position of Mars.

Now look at the positions in the fourth month. The line through point 4 is extended to the stars. But point 4 among the stars is *behind,* or west of, point 3. To an observer on the earth,

Mars has moved to the west—or backward—during this month. Of course, Mars has not really moved backward at all. It just seems that way to an observer looking at it from the earth.

Here is an activity that will help you understand this idea. Have one person stand about ten feet from the chalkboard at the front of the room, while you stand about fifteen feet away from it. Put as many numbers as you can on the board, about one foot apart, starting with 1. Now the person is to walk slowly in front of the board toward one side of the room, keeping about ten feet from the chalkboard all the time. He represents Mars. The numbers on the board represent stars. You will represent an observer on the earth. After the Mars person has walked about four steps, you can start walking about twice as fast as he is walking. In other words, you take two steps while he is taking one step.

During your walk, notice what number you see behind your friend as you look toward him at the chalkboard. Notice that when you start to pass him, it suddenly appears as though he has stopped. Then it appears as though he were moving backward. The numbers seem to reverse direction.

In the solar system, when the earth passes Mars, Mars seems to move backward against the background of stars, as you saw in the diagram on page 154.

Still another way to think of this idea is to imagine yourself in a train on a track in a station next to another train. Neither train is moving. Now your train starts to move forward slowly and smoothly. You may not feel the movement, and you may not realize that your train has started. What you appear to see is the other train moving backward. Actually, your train is moving forward while the other train is standing still.

Both the earth and Mars move "forward." But the earth moves faster. When we pass Mars it looks as though Mars is moving backward.

You have seen how Mars's backward motion is explained by the Copernican theory. But there is a second puzzling fact about the appearance of Mars. Mars seems brightest in the middle of its backward motion. You have seen how Ptolemy explained this fact with his epicycles. As Mars moves backward, it loops in toward the earth. As it gets closer to the earth, it appears brighter. How can the brighter appearance of Mars when it seems to move backward be explained by the sun-centered model? Study the diagram on page 154 to figure out the answer.

Which Theory to Choose?

Both the earth-centered model and the sun-centered model account for the facts you have read about so far. Both models predict where a planet will be seen. Both models account for the motions of the sun, moon, and stars. When Copernicus suggested the new model, most astronomers saw no special reason for accepting it. Ptolemy's model accounted very well for all the facts. Why change theories?

Copernicus liked his theory better than Ptolemy's because the sun-centered model had fewer circles. Copernicus thought of the sun at the center of the universe with the planets moving around in perfect circles. Ptolemy thought the earth was at the center and had to put the planets on circles drawn on circles. The simpler model of planetary motion seemed a better idea to Copernicus, and this was the only reason given for accepting the new theory. An astronomer in 1550 would choose the Coperni-

Above is Tycho Brahe in his observatory in 1602. Above right is Johann Kepler, a German astronomer, discussing his discovery of planetary motion with Emperor Rudolph II. Below is Galileo. Learn about the findings each of these men made and how the findings have helped us to understand the universe.

can model if he liked a simple system. He would choose the Ptolemaic model if keeping the earth at the center of everything were more important to him than a simple system.

Nearly 300 years after the death of Copernicus, scientists found other reasons for accepting the Copernican model. You will discover some of those reasons as you read on in this unit.

Using What You Have Learned

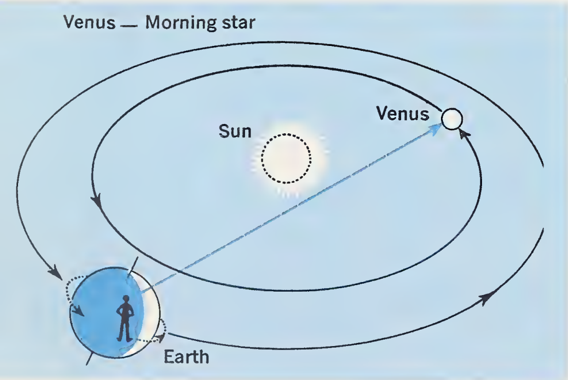
1. Check your local paper to find out which planets can be seen in the night sky this month. Look for them. Notice in which part of the sky you see them. Is each planet always found in the same position in the sky? Why? Keep records and compare the planets' positions with their positions next month.

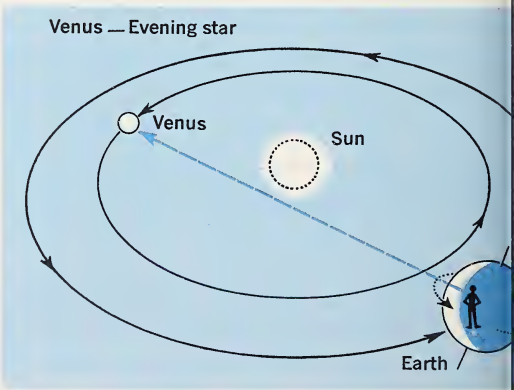
2. Can Mercury be seen as easily as Venus, Mars, and Jupiter? Why?

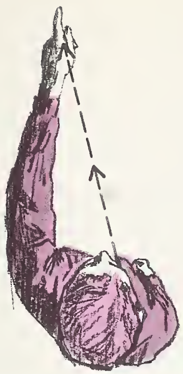
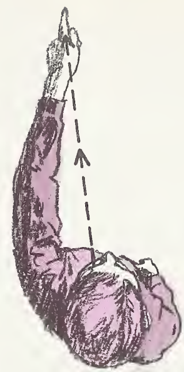
3. Prepare a special report on the life of Copernicus. Include such items as his nationality, where he went to school, what he studied, and reasons that might have led him to invent a new theory.

4. Sometimes we see Venus as a morning star, just before sunrise. At other times it is the evening star, seen just after sunset. Use the diagrams below to explain why Venus is sometimes a morning star and sometimes an evening star.

5. Why is it never possible to see Venus at midnight? Use the diagrams below to help you answer this question.





Locating Things in Space

Hold out one finger at arm's length. Look at it with one eye. Now, holding your finger still, shut the eye that was open and open the eye that was closed. What do you notice about your finger?

Now try this. Have a classmate hold a yardstick about three yards in front of you. Notice what you see directly behind the yardstick. Now take a big step sideward while your classmate holds the yardstick in the same place. Look at the yardstick again. What do you see directly behind it? Although the yardstick has not moved, it *seems* to have moved because you looked at it from two different places.

In the first activity, why did your forefinger seem to move against the background? It seemed to move because you looked at it from two different positions, the positions of each of your eyes. This apparent shift in position of an object when viewed from two different locations is called **parallax** (PAR-uh-lakss).

You can observe parallax in your classroom. Stand a book on your desk. Look at some nearby object from one edge of the book. Now look at the object from the opposite edge. Notice how the object seems to move against its background.

Now that you know about parallax, you realize that you have noticed it all your life. Can you think of how parallax has been useful to you, even though you may not have been aware of its usefulness before?

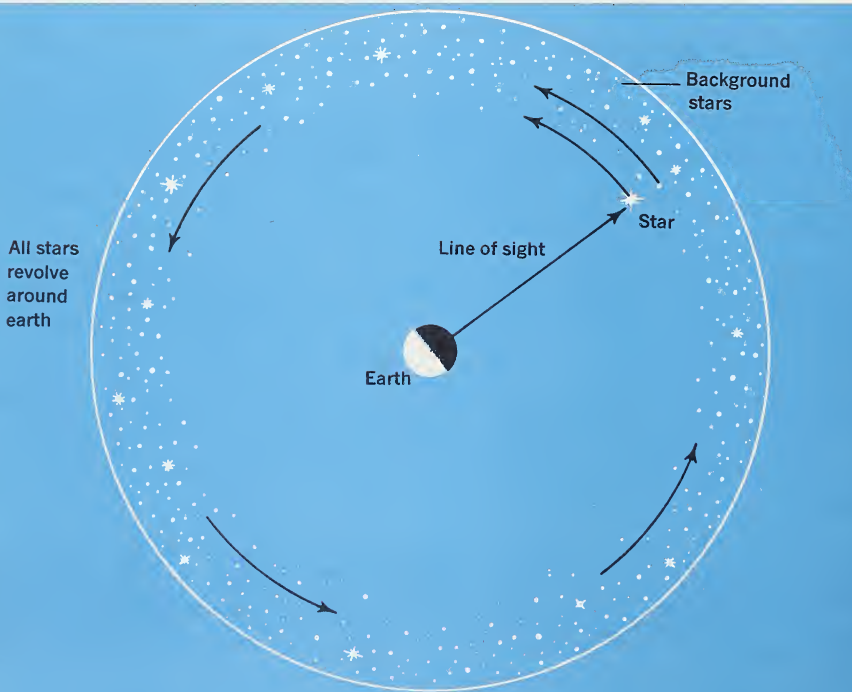
Copernicus and Parallax

Let us consider again the two models of the solar system. In the picture is an earth-centered model. You will recall that in this model the earth does not move. Imagine that you are on this earth and that you have selected a star to look at. In this model the entire sphere of stars goes around the earth. Should the background for any star ever change?

If the earth were at the center of everything, and if all objects in the sky went around the earth, then you would notice no parallax among the stars. Being on the earth would be like being at the center of a huge bicycle wheel. The wheel might turn, but things that were close to the center would not seem to move against the background of things farther away.

In the earth-centered model, near stars would not change position against distant stars.

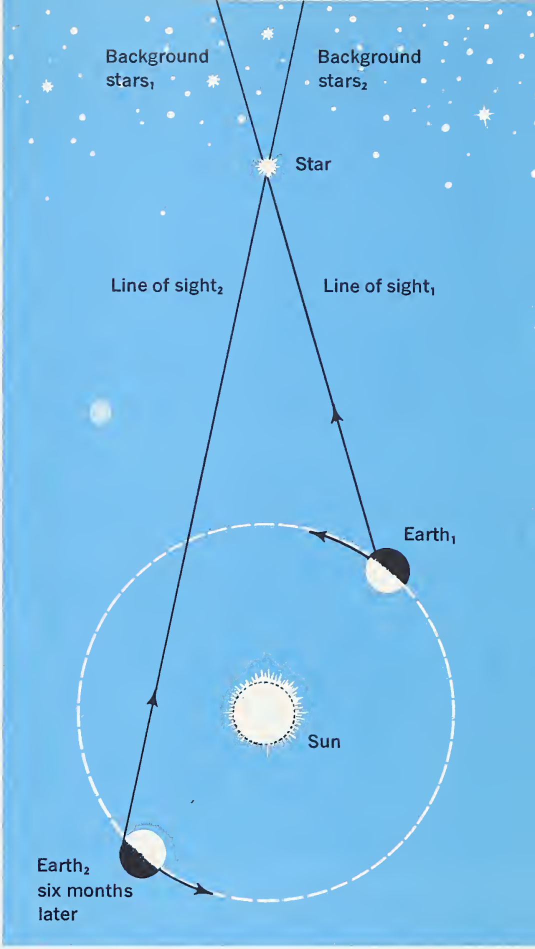
But what can we expect in the sun-centered model? Should near stars seem to shift position according to Copernicus' theory?



In the diagram on the right, the earth travels around the sun. You can see a line from the earth to a near star. Following the line you see the background against which this star appears. What is the position of the earth six months later? At that time the earth has traveled halfway in its orbit around the sun. It is at the bottom of this diagram. Now you want to look at the same star. The second line shows where you would expect to see this star from the opposite point on the earth's orbit. Because of parallax, you would expect to see the star against a different background. Does this happen?

The parallax test was put to the Copernican model. Astronomers said that if the earth moved around the sun, parallax would appear when you observed a close star six months apart. If there were no parallax, then the earth must be standing still. However, careful observations of nearby stars showed *no* parallax. For this reason, many great astronomers rejected Copernicus' theory.

Parallax for a nearby star was not detected for nearly three hundred years after Copernicus' death. The stars are very far away, much farther away than Copernicus or other astronomers of his time imagined. Because of their great distances from the earth, it is difficult to measure parallax. Let us now find out the relationship between parallax and distance. You will do an experiment to find out. After you finish this experiment, see if you can think of another experiment to help you to find out the relationship between parallax and distance.



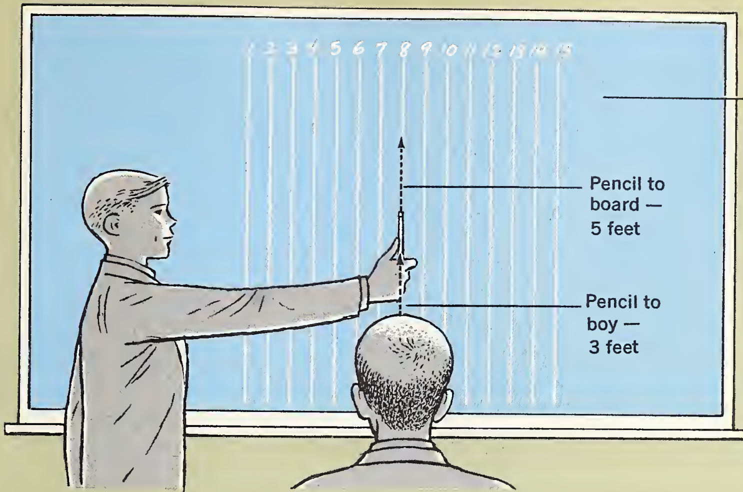
What Is the Relationship Between Parallax and the Distance to an Object?

What You Will Need

chalkboard pencil yardstick

How You Can Find Out

1. Make a series of about fifteen vertical lines about one inch apart across the chalkboard. Number each line as shown in the drawing. Have a classmate hold a pencil about five feet in front of the chalkboard. During the activity neither your friend nor his pencil must move.
2. Now stand about three feet from the pencil looking toward the lines on the chalkboard.
3. Look at the pencil first with one eye, then with the other.
4. Notice the parallax. Measure it by noting against which line the pencil appears when you view it with one eye. Then note against which line it appears when you view it with the other eye. Perhaps it appears near line 13 with your right eye and near line 8 with your left. For purposes of this activity, call this measurement a parallax of 5 (13 − 8 = 5). Make a record of the actual parallax you get at three feet from the pencil.
5. Now step back three feet to put yourself six feet from the pencil. Be sure your friend does not move.
6. Repeat the observation. Look at the pencil first with one eye, then with the other.
7. Make a record of this parallax. Remember that this observation is made six feet from the pencil.
8. Now step back three more feet. You are now nine feet from the pencil. Record the parallax measurement.
9. Step back another three feet. Record the new parallax.
10. Now try to answer the questions on the next page.



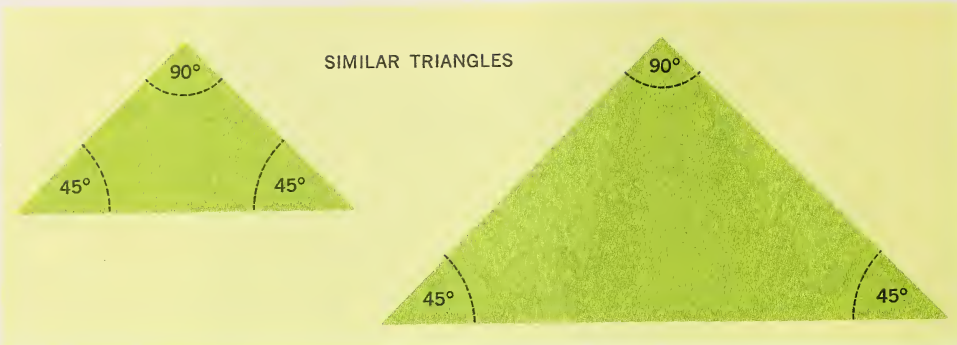
Questions to Think About

1. Examine your results for all the distances. What do you notice about your parallax measurements as you move farther away from the pencil?
2. What do you think you would observe if you moved about 100 feet from the pencil, looking at it first with one eye, and then with the other? Do you think you would detect any parallax?

Even the nearest star is so far away that its apparent shift of position against the background of the farther stars is very slight.

The slight parallax of a near star was not measured until the 1830's. In 1838, the German astronomer Friedrich Bessel, whom you read about on pages 24 and 25, measured the parallax of the star called 61 Cygni. You can review how he did this by rereading the Pathfinders in Science section on pages 24 and 25. By the time he lived, finer instruments had been developed than those available at the time of Copernicus, and so the proof of Copernicus' theory by using parallax became possible. A star does shift its position against its background when viewed from the earth. Copernicus' idea that the earth was moving explained the shift.

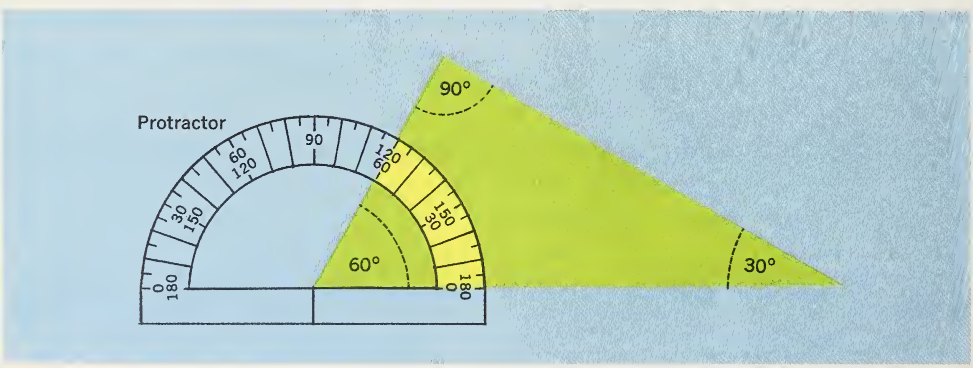
In the next part of this unit, you will find out how parallax measurements can be used to find actual distances.



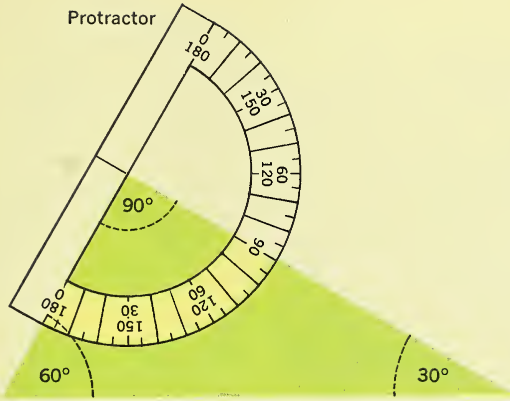
Using Triangles to Measure Distances

You can use parallax to measure how far away objects are. But first you must know a few facts about **triangles.** A triangle is a closed figure with three straight sides and three angles. In the drawing above are two *similar* triangles. Although the sides have different lengths, the triangles have the same shape. Their angles are equal. The size of an angle is measured with a **protractor,** as you see in the drawing below.

Draw two triangles, each on a separate sheet of paper. Start by making the bottom, or base, of one triangle exactly 2 inches long. Make the base of the other triangle exactly 4 inches long. Make an angle of 60° at the left end of each base. Make a 30° angle at the right end of each base. Extend the lines on each sheet of paper until you have made triangles.



 Use this page and the next three as the basis for oral work in class. Proceed one paragraph at a time with the directions, making sure that each step is understood before



You know certain facts about these triangles that you have drawn. Each triangle has one angle of 30°. Each triangle has one angle of 60°. The base of one triangle is 2 inches. The base of the other triangle is 4 inches. What else can you find out about these triangles?

Carefully measure the third angle on each triangle with a protractor. These angles should both be 90°. In every triangle the sum of the measures of the angles is 180°. This is true no matter what its shape or size. In the triangles you have drawn, $60° + 30° + 90° = 180°$.

What else can you find out about these triangles? How does the length of one of the sides of one of the triangles compare with the length of the corresponding side of the other triangle? You know that the base of one is exactly twice as long as the base of the other. What about the other sides? Measure and compare the lengths of the other sides of the triangles. What do you discover?

The facts that you have discovered about similar triangles can be used to measure distances. Imagine that a surveyor wants to measure the distance across a deep gorge. He cannot stretch a tape measure across the gorge without falling in.

What he needs is a triangle similar to the one shown on page 166. First

going on to the next. Careful supervision will develop ability to read this type of material which pupils will increasingly encounter in higher grades.

he finds two points (A and B) to form a *base line.* He measures the actual length of the base line. Suppose it is 100 yards long. Then he measures the angle at A by sighting a tree on the opposite side of the gorge. Next he measures the angle at B by sighting the same tree. Suppose these angles are 70° and 80°.

On a sheet of paper he could make a similar triangle which is really a scale drawing of the imaginary triangle formed by the base line of 100 yards and the two angles. For his scale drawing he makes his base line 10 inches long. Ten inches represent 100 yards, so 1 inch represents 10 yards. Then he draws the 70° and the 80° angles on his scale drawing to complete the similar triangle.

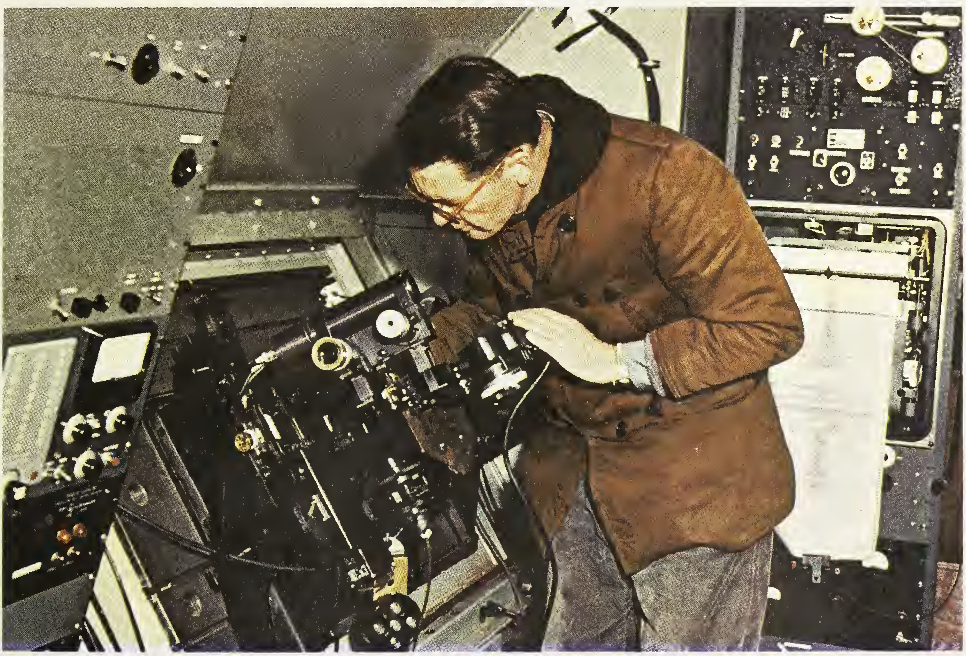
Perhaps you can make the scale drawing for this example on the chalkboard of your classroom. Let one inch represent 10 yards, so that 10 inches represent 100 yards. Then draw angles of 70° and 80° and complete the triangle. Now measure the sides. By multiplying the lengths of the sides by

10, you can find the distance across the gorge in yards.

Now use the scale drawing to answer these questions: How far is it from A to the tree? How far is it from B to the tree? What is the shortest distance across the gorge? What measurement must you make on your scale drawing to find this distance?

Astronomers use a method similar to this one for measuring distances in space. First they need a long base line. Then they measure the angle from each end of the base line to the planet whose distance from the earth they want to learn. They might then draw a similar triangle, but it is not necessary. Once they know three facts about the huge triangle—the length of the base line and the sizes of two angles—they can get the rest of the information about the triangle from charts. The basic method, however, is just like the surveyor's method.

Astronomers use complicated instruments to measure distances to the stars. Look up *spectroscope* in a high-school science book. How do astronomers use the spectroscope?



Using What You Have Learned

1. Find the relationship between parallax and the length of the base line. In the activity on page 162, you found out that parallax gets smaller as the distance to the object increases. Now plan an activity to discover how parallax changes if the base line gets longer. For this activity, keep the distance to the object the same.

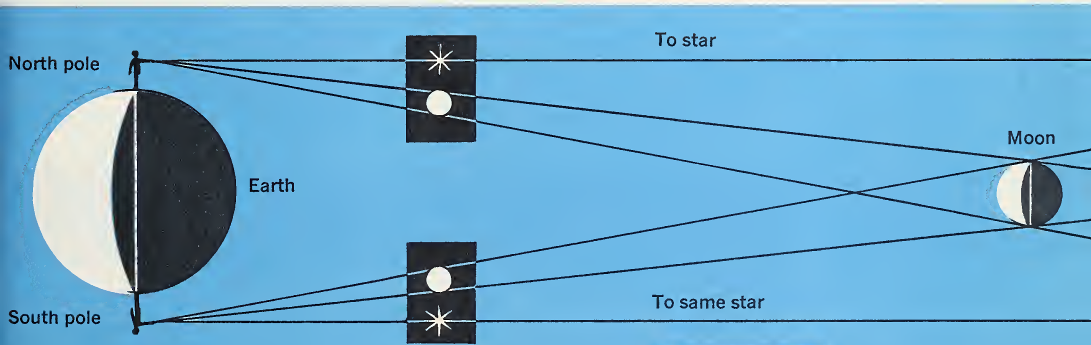
2. Measure the distance to an object in the schoolyard using the method of similar triangles. (Perhaps you can find the length of the schoolyard by measuring the distance from one end to a post at the other end.)

3. Check your results in activity **2** by measuring the distance to the object directly. That is, measure the distance by pacing it off or using a yardstick. How does the result compare with the answer you got in activity **2**? What are some places where you might have made errors in activity **2**?

4. On page 164, you read about similar triangles. You also read that scientists need not actually draw similar triangles to get the information they need. When astronomers use the parallax method, they need to find only certain facts. Then they can figure out the others without actually drawing similar triangles. What measurements does an astronomer need to make to use the parallax method?

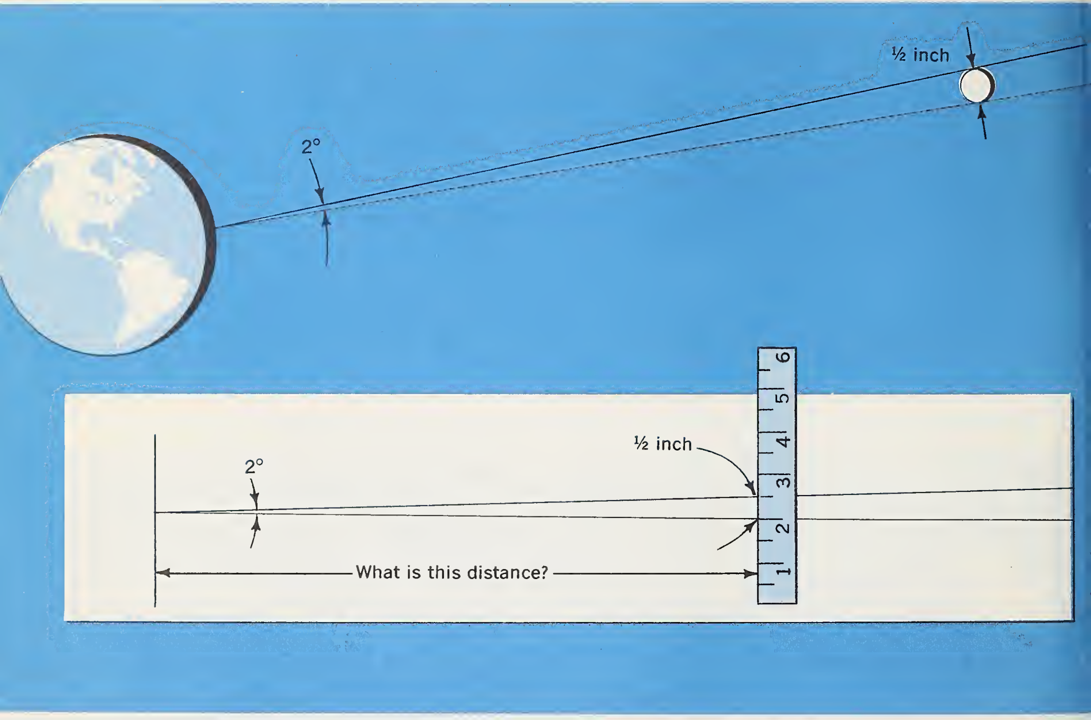
The distance from the earth to the moon was first found by using the parallax method. The main difficulty in finding this distance lies in finding a base line that is long enough. A base line of 100 yards, or even one of 100 miles, is too short, because the parallax angle is not large enough to be measured. To find the distance to the moon, a base line that is thousands of miles long is needed. Before you look below, can you tell what might serve as such a base line?

a. Now suppose we could use the diameter of the earth for a base line. To do this, you would need to place yourself at the North Pole and a friend at the South Pole. First, you both would sight at the same star. Even the nearest star is so far away that you would both be pointing in the same direction. (The actual difference in direction is so small that we could not measure it.) The picture shows you and your friend looking at the star with telescopes so that the angle between the lines of sight and the earth's axis is 90°. Then, at a certain time, you both would sight at the moon. Now you no longer would point in the same direction as your friend. You each would measure the angle between the direction to the moon and the direction to the star. You each would find that the angle is about 1°.



b. Using a protractor, draw an angle of 2° on a long sheet of paper. (You will need one about twenty inches long. You can tape two pieces together if you do not have one piece long enough.) Draw the angle as carefully as you can and make the lines very straight. Then measure the distance between the lines and find the place where they are ½ inch apart.

The diameter of the earth is about 8,000 miles, so if this ½ inch represents 8,000 miles, then 1 inch represents 16,000 miles. Now measure the distance from where the lines are ½ inch apart to where they meet. From this measurement, what do you get for the distance from the earth to the moon?



Finding the Sizes of Objects in Space

Similar triangles can also be used to measure the sizes of planets, the sun, and the moon. By size, the astronomer means the distance across the planet, sun, or moon through its center, that is, the *diameter*.

You probably know that you cannot learn very much about the actual size of an object from the size it *seems* to be. Try this. Hold a penny between your eye and the classroom clock. Hold it just far enough away so the penny blocks your view of the entire face of the clock. In this position, the penny and clock *appear* to be the same size. But of course the diameter of the clock is much greater than the diameter of your penny.

Let us see if you can measure the diameter of the clock if you know how far away it is.

By using similar triangles, you can find the *size* of an object if you know *how far away* it is.

EXPERIMENT

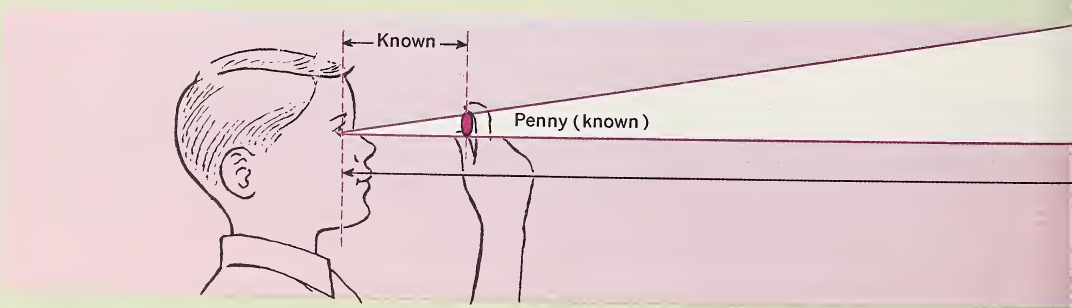
How Can You Find the Size of an Object by Using Similar Triangles?

What You Will Need

penny	yardstick or tape measure
classroom clock	

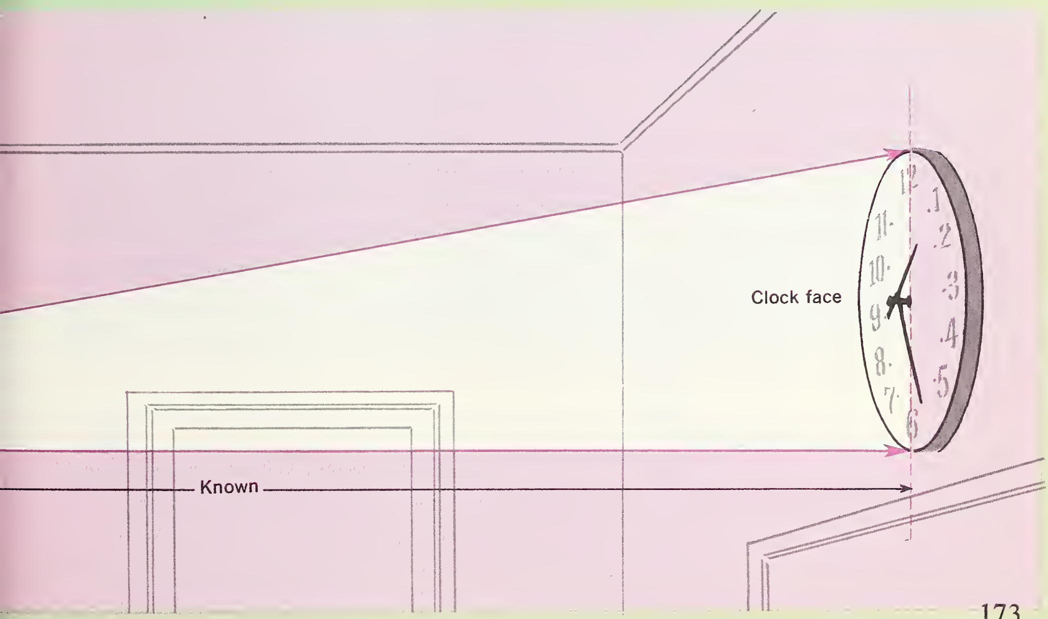
How You Can Find Out

1. Stand in a single spot for this activity. Measure the distance between this spot and the classroom clock with a yardstick or tape measure. If your classroom has no clock, cut out a circle about the same size as a clock and tack it on the bulletin board.
2. Hold a penny between the clock and your eye. Hold it at exactly the distance where the penny completely and fully blocks your view of the face of the clock, but no closer.
3. Have a classmate measure the distance between your eye and the center of the penny.
4. Carefully measure the diameter of the penny.
5. Notice that you have measured certain sides of similar triangles. One triangle is marked out by your eye and the opposite edges of the penny. The other triangle is outlined by your eye and the opposite edges of the clock. Notice also that these particular similar triangles share one angle, the one near your eye.
6. Now answer the questions on the next page.



Questions to Think About

1. Remember that if one side of a triangle is twice as long as the corresponding side of a similar triangle, the other sides of that triangle are twice as long as their corresponding sides, too. Look at the diagram again. You know two facts about the small triangle. You know the distance of one side (the distance between your eye and the penny). You also know the distance across the end (the diameter of the penny). You know one corresponding side of the big triangle—the distance between your eye and the clock. *Exactly* how many times longer is the distance to the clock than the distance to the penny? Figure it out.
2. Your answer tells you how many times bigger the clock is than the penny. What is the diameter of the clock?
3. Can you think of other ways in which you can find the size of an object by using similar triangles?

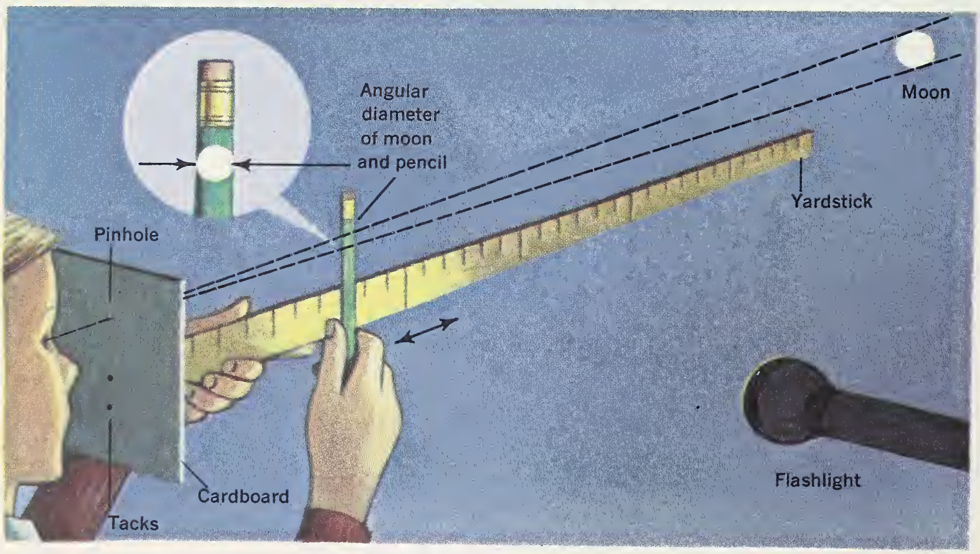


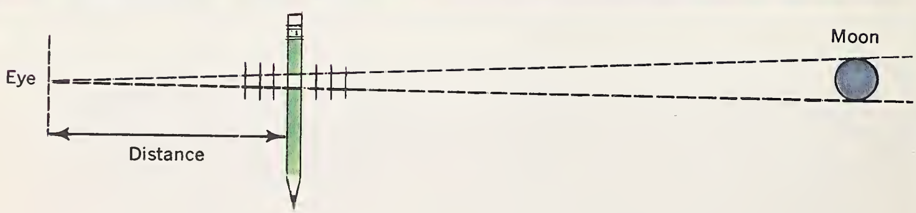
You can use the same experimental method to find the size of the moon.

Here is a diagram of how you can use a pencil, a yardstick, and a piece of cardboard to measure the size of the moon. This activity is best done on a dark night when there is a full moon. Tack a sheet of cardboard to the end of a yardstick. Put a small slit in the cardboard. Point the yardstick at the moon as you see in the diagram.

Now move the pencil along the yardstick until it *just* blocks your view of the moon. How far is the pencil from your eye? Next measure the diameter of the pencil.

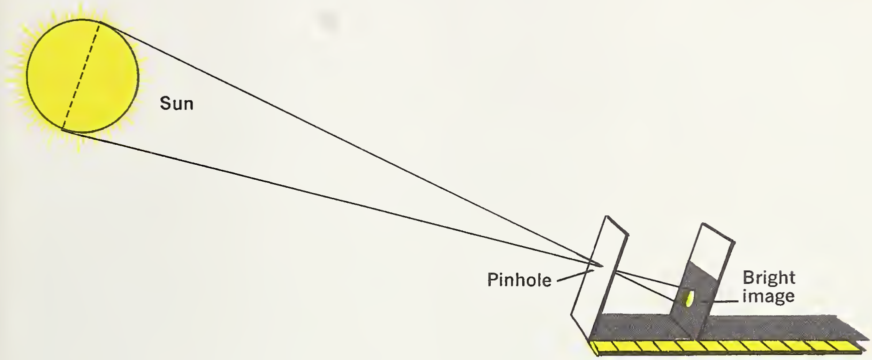
You now have three facts that correspond to the three facts for figuring the size of the classroom clock. You know the distance to the moon (240,000 miles), the distance to the pencil, and the diameter of the pencil. What is the diameter of the moon?





Using What You Have Learned

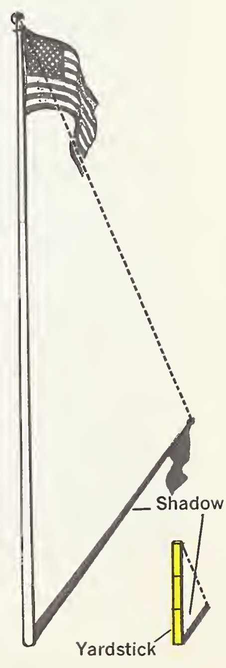
1. Practice the method of using similar triangles to find sizes. Cut out circles. See how accurately you can figure out their diameters.



2. You can use similar triangles to find the size of the sun. But since the sun is too bright to look at directly, the method is slightly different from the one for finding the size of the moon. You can look at the sun's image instead of the sun itself. Here you see a diagram of the method. Be sure the pinhole is just the right size to form a bright image. Be sure also that both pieces of cardboard face the sun squarely.

Can you find the similar triangles? Measure the distance between the pinhole and the sun's image. Measure the diameter of the sun's image. The sun is about 93,000,000 miles away. How big is it?

3. Look for the similar triangles in this activity. If you find them, you can figure out a method for getting the height of a flagpole, a tree, or a building without climbing to the top. What is the method? Use the diagram for clues.

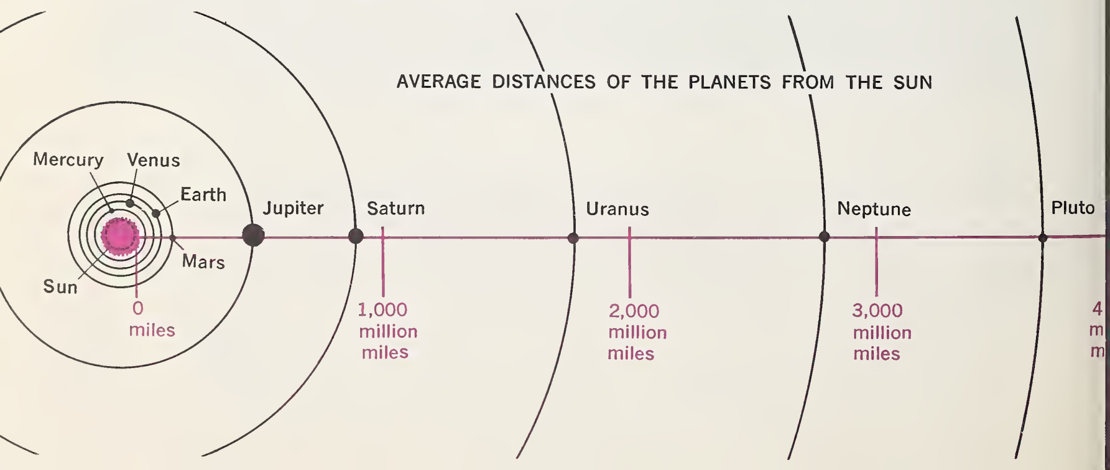


Viewing the Universe

By using the methods described in this unit—and many other methods as well—astronomers have arrived at a picture of the universe that Ptolemy would hardly recognize. For one thing, distances are much greater than he ever imagined. If you could travel at 1,000 miles per hour toward the *nearest* star other than the sun, it would take you about 3 million years to get there. In fact, distances beyond our solar system are so great they are measured in **light-years.** One light-year is the distance traveled by light in one year. The speed of light is about 186,000 miles per second. To find out how far light travels in a year, you must multiply 186,000 miles by the number of seconds in a year! The answer is about 6 million million (6 trillion) miles—which written out looks like this: 6,000,000,000,000. The nearest star is about 4½ light-years away.

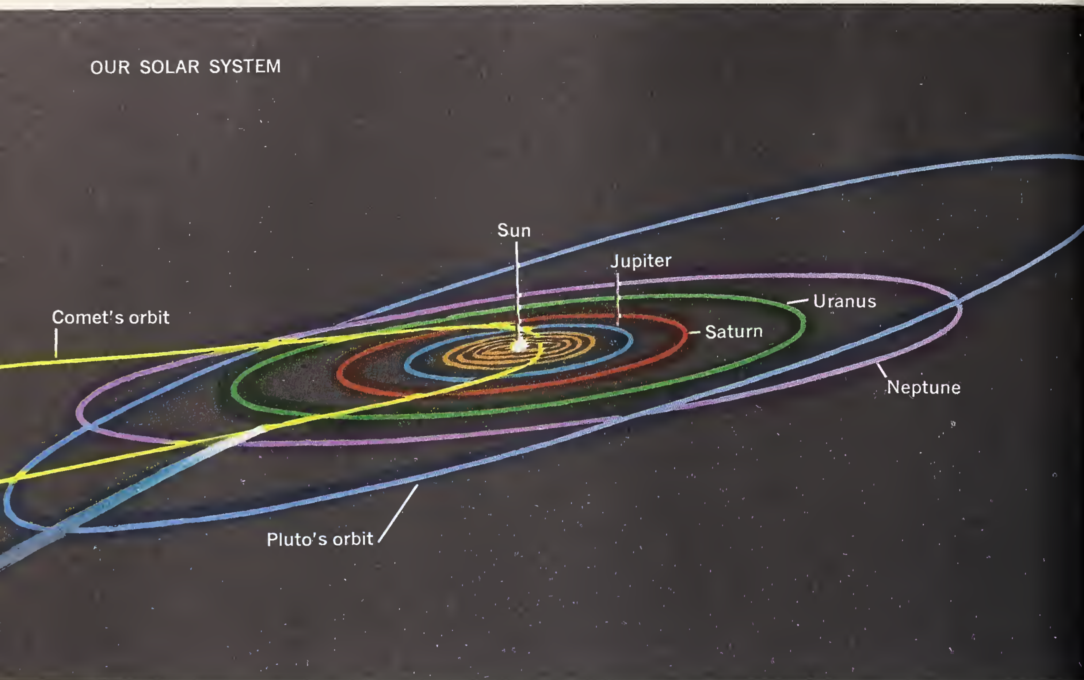
Ptolemy would even be surprised by distances within the solar system and the small sizes of the planets compared with these distances. Imagine a model of the solar system. Imagine on this model that the earth is 1 inch in diameter. (On this scale, 1 inch equals about 8,000 miles.) Then the sun would be about 3 *yards* in diameter. The earth would be about 320 yards from the sun. Jupiter would be about 1½ miles from the sun.

Of course Ptolemy would have been most surprised by the fact that the earth is not at the center of everything. The sun is at the center of the system. Nine planets go around the sun in paths that are almost circles. Many of the planets have moons: the earth has one, Mars has two, and Jupiter has twelve. In the table on page 177, you will find some more facts about the planets.



Sizes of the Planets and Distances from the Sun

Planet	Distance from the Sun (miles)	Diameter of the Planet (miles)
MERCURY	36,000,000	2,900
VENUS	67,000,000	7,600
EARTH	93,000,000	7,900
MARS	142,000,000	4,200
JUPITER	483,000,000	87,000
SATURN	886,000,000	72,000
URANUS	1,783,000,000	29,000
NEPTUNE	2,794,000,000	28,000
PLUTO	3,670,000,000	3,600



If you could view the solar system from afar, you would see that it is very flat. Its shape is something like a phonograph record—a disk. Only Pluto and the comets move out of the disk.

Within the disk, you would see all the planets moving in the same direction around the sun—counterclockwise when viewed from the "top." But the planets do not all move at the same speed. Those closer to the sun move faster. For example, Mercury goes around the sun in 88 of our days. Its orbit is smaller than the earth's, and its speed is greater. The earth, whose orbit is greater and whose speed is less, orbits the sun in 365 of our days.

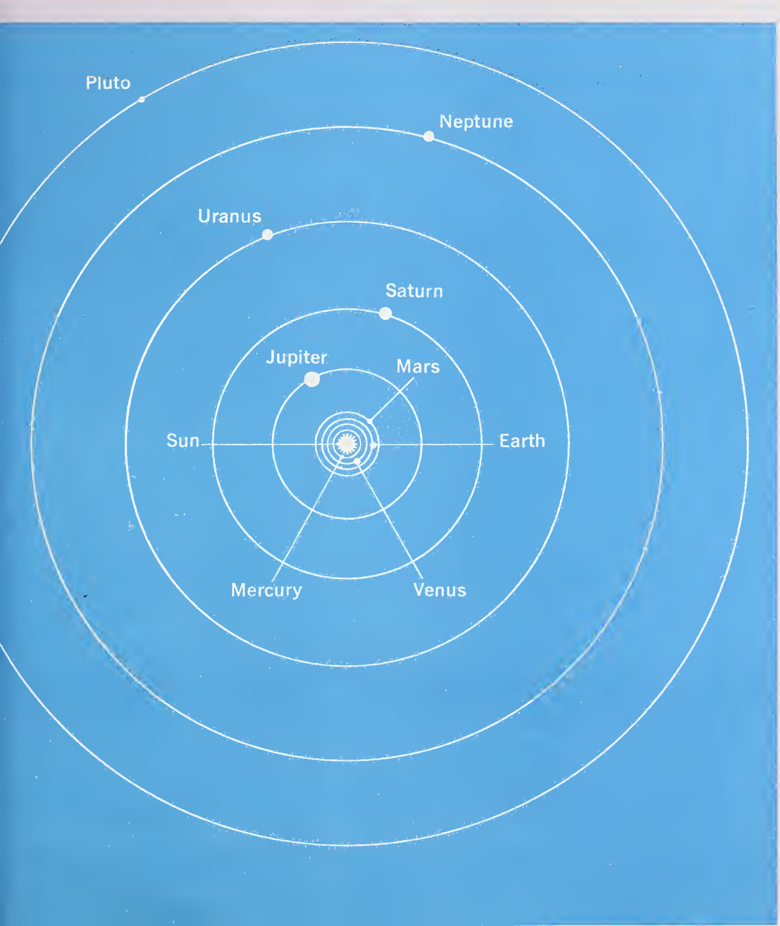
It takes Mars almost two of our years to go around the sun once. It takes Saturn close to 30 years. Neptune goes around in about 164 years.

As the earth moves around the sun, it travels about 291 million miles. It does this once each year, or in 365 days. How far does the earth travel

each day? The planet Mercury travels about 113 million miles as it goes around the sun in 88 days. How far does Mercury travel each day? How much faster does Mercury travel than the earth? As Neptune travels around the sun, it goes about 8,782 million miles in 59,860 days. How many miles does it travel each day? How does its speed compare with the speeds of the earth and Mercury?

Of course, most of what you would see if you could view the entire solar system would be space. The planets are tiny compared with the huge distances between them.

TIME IT TAKES PLANETS TO GO AROUND THE SUN



Pluto	248 years
Neptune	164 years
Uranus	84 years
Saturn	29 years
Jupiter	12 years
Mars	1 year and 241 days
Earth	365 days
Venus	215 days
Mercury	88 days

PATHFINDERS IN SCIENCE

A. C. Bernard Lovell

(1913–   ) England

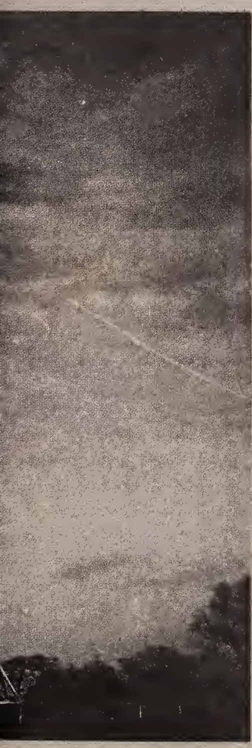
For hundreds of years astronomers have used telescopes to see into space. With their telescopes they have discovered new planets, stars, and comets. They have discovered what the stars are made of and how the stars are born and die.

But astronomers in this century were dissatisfied. Looking into space from the surface of the earth is like looking into a garden through a very dirty window. The earth's atmosphere acts as a filter, blocking off most of the starlight that reaches the earth. What astronomers wanted was a way to open the window.

There was a way. In the 1930's, scientists using sensitive radio equipment discovered by accident that they were receiving faint, mysterious noises in their radios. They discovered this noise came from outer space. Astronomers were certain that this noise was caused by the stars, in exactly the same way that a flash of lightning can cause static in an ordinary radio receiver. But they could not be positive about this until they could pinpoint exactly where in the universe the noise was coming from.

Unfortunately, they could not learn anything at first, because there was no way to focus these faint noises as they could focus starlight in their telescopes.

Bernard Lovell was an English scientist who was born the son of a poor postman in a small village. During World War II he helped design radar equipment. Lovell became interested in these noises from outer space. He knew that it would



be necessary to build a curved reflector like a radar antenna to focus these faint noises accurately. He convinced the British government that it would be worthwhile to build a reflector that was 250 feet in diameter (almost the size of a football field). The reflector would focus the faint noises into a specially designed radio receiver. Because the radio receiver was very sensitive, the scientists could focus the reflector very accurately. This *radio telescope* was built in the English countryside, near a place called Jodrell Bank.

The Jodrell Bank radio telescope has done all that Lovell hoped it would. He has discovered new kinds of stars that astronomers never knew existed. The radio telescope has also revealed a thin, cold hydrogen gas in space, which could not be seen with optical telescopes because it does not give off light. But the radio waves that this gas generates, like those from the stars we can hear but not see, pass through the interstellar dust and debris to be picked up on earth.

For his achievements, Bernard Lovell was knighted by Queen Elizabeth II.

Galaxies

For about forty years, astronomers have known that our sun is one star in a large group of stars called a **galaxy.** A galaxy, like the solar system, is very flat and consists mostly of space.

Our galaxy, which is known as the Milky Way Galaxy, is relatively as flat as a half-dollar, although it is slightly bulged in the middle.

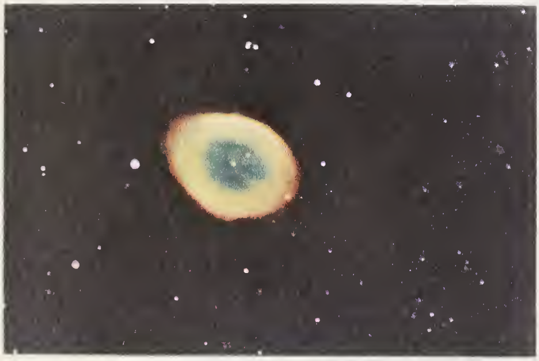
Distances between stars in a galaxy are difficult to imagine. Imagine that the sun is the size of a ping-pong ball. On this scale, the nearest star is about 400 miles away. The average distance between stars in this ping-pong ball galaxy is about 400 miles. And there are about 100 billion stars in the galaxy. Thinking of this model gives you an idea of the size and emptiness of a galaxy.

Nebulae is a Latin word for clouds. It refers to distant hazy spots in the sky. Many are faraway galaxies like our own; others are clouds of dust or gas within our galaxy.

Great Nebula in Orion

Trifid Nebula in Sagittarius

Ring Nebula in Lyra



Great Galaxy in Andromeda

Let us try a different scale for the galaxy. Imagine that our sun is the size of a grain of sand. In this model, the stars are about five miles apart. If you can imagine 100 billion sand grains five miles apart spread out in a flat disk, you have a pretty good idea of the galaxy.

Our galaxy is about 100,000 light-years in diameter, and the sun is about 30,000 light-years from the center. That puts it near one edge. The space between stars in the galaxy is not exactly empty. Bits of dust and hydrogen gas float in the space between the stars.

In the galaxy, each star has its own orbit around the center of the galaxy just as each planet has its own orbit around our sun. Stars near the center of the galaxy move more rapidly than stars near the edge. Thus, the stars in the galaxy slip by each other as the centuries pass. Every star in the galaxy has different neighbors now from those it had a billion years ago.

TIME AND SPACE

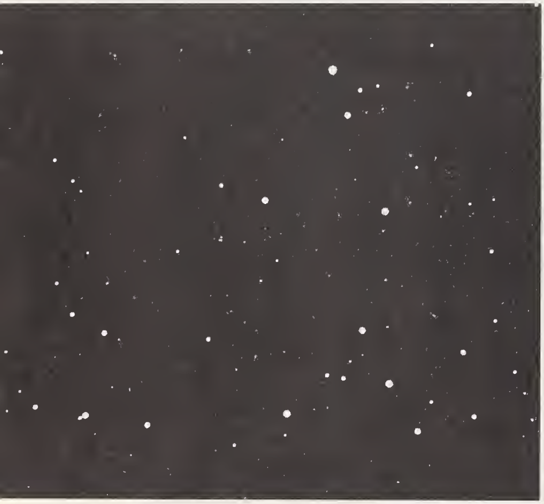
Tonight, look at the stars. You will see each of them just as it was at some time in the past. The world's largest telescope can photograph objects two thousand million light-years away. This means that the light from these objects has been traveling through space for two thousand million years.

What was happening on the earth when the starlight that made each photograph below started traveling toward us? You can see in the picture below each photograph of the stars.

CLUSTER OF GALAXIES IN HYDRA

700 Million Light-Years Away

There were no hard-shelled forms of life on the earth 700 million years ago. But when the light from these galaxies had traveled one third of the distance toward us, trilobites were found in the seas.



CLUSTER OF GALAXIES IN CORONA BOREALIS

240 Million Light-Years Away

At the time light from this cluster started toward us, primitive amphibians were found in freshwater ponds and streams. Above, you see a photograph of the skull of one such amphibian, Diplocaulus.

THE GREAT CLUSTER IN HERCULES
35,000 Light-Years Away
This tooth from an ice-age elephant is 35,000 years old. When light from the Great Cluster in Hercules started toward the earth, these elephants lived near the great ice sheet that covered much of North America.

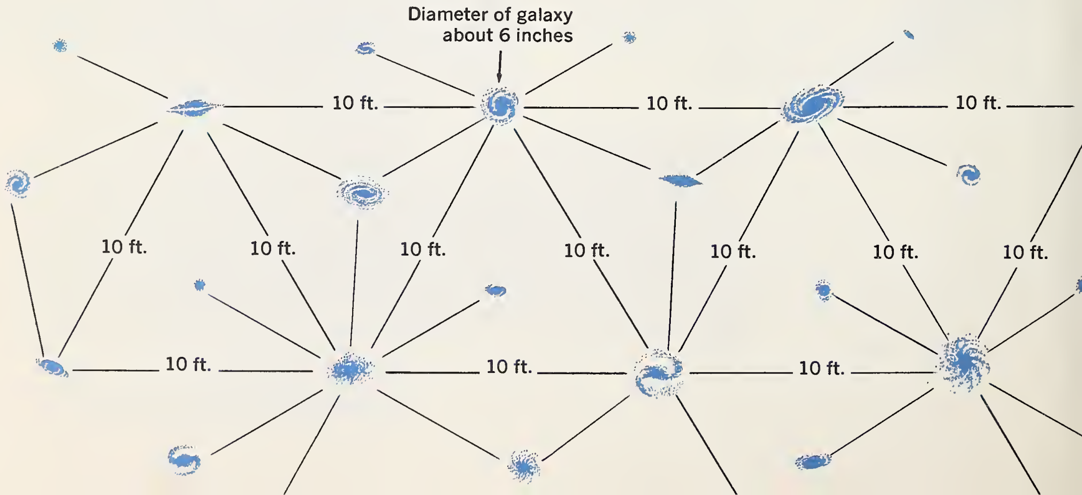
PLANETARY NEBULA IN AQUARIUS
600 Light-Years Away
This nebula with its jet-like streamers and luminous ring is one of the closest to us. If you look at it tonight, you will see it as it was when Geoffrey Chaucer was beginning to write his *Canterbury Tales,* in 1387.

Almost all the objects you see in the sky on a clear night are in our own galaxy. But astronomers have studied thousands of faintly visible objects with telescopes and found these objects to be part of other galaxies. Thus, the universe is not made up of our galaxy alone, but in fact of billions of galaxies, each one with billions of stars!

Galaxies extend outward in all directions from our own as far as we can see with our most powerful telescopes. Nearer ones are about 150,000 light-years away. But galaxies have been discovered 5 billion light-years away. Some are surely farther away than that and may never be detected.

It is usually helpful to imagine a small model when thinking about astronomical systems. Here is a model of the universe for you to think about. If a single galaxy containing 100 billion stars were shrunk to the size of a fried egg, about six inches across, then the average distance to the next galaxy would be about ten feet. Imagine countless objects the size of fried eggs tipped in all directions, each one about ten feet from the next.

In one of these billions of galaxies, out near the edge, there is a medium-sized star. It moves around the center of the galaxy as do the other 100 billion stars in this galaxy. Looking very closely with special instruments, for the objects are small, we see nine planets that go around this star. The planet that is third in distance from the star is covered mostly by water. This planet has a moon. Every once in a while a tiny new satellite is shot off from this planet, and, like the moon, it moves in orbit around the planet year after year. Would you predict that in time we would see an object leave that planet and arrive on the moon, or even at a point on another solar system?



Using What You Have Learned

1. Make a papier-mâché model of several galaxies. Make each galaxy about six inches across and about ten feet from any other galaxy. Maybe you can fit four or five in your model. Remember that galaxies extend outward in all directions from each other.

2. If you live near a planetarium, plan to visit it when the program is about different models of the solar system.

3. Prepare a special report on comets. How are comets different from planets?

4. How old is our solar system?

5. We get information about astronomical objects from the light they give off. Light travels at 186,000 miles per second. At this speed light reflected from the moon reaches us in a second and a half. In other words, when you see the moon you see it the way it looked a second and a half ago. You see the sun the way it looked about eight minutes ago. You see the nearest star the way it looked four and one-half *years* ago. Can you see that as you look out in space you are looking backward in time? Discuss this idea with your classmates.

6. Why does our Milky Way Galaxy seem to be a narrow band of stars across the sky?

7. Use a part of your classroom bulletin board for sky studies. Form a committee to tack news about the sky on the board every week. You might tack such things as clippings from newspapers and magazines about the sky, daily or weekly timetables of sunrise and sunset, special events such as an eclipse or a meteor shower, directions for making a telescope, and photographs made by classmates of sky objects.

WHAT YOU KNOW ABOUT

Astronomy

What You Have Learned

Models help scientists explain their ideas. Astronomers have used models to help them explain the motions of the planets in our solar system.

The **Ptolemaic** model is an earth-centered model of the solar system. The **Copernican** model is a sun-centered model. Both models were designed to explain the **retrograde motion** of the planets. Ptolemy believed that each planet went around the earth in two circles. One was a large circle that carried it around the sun. The other was a small circle the center of which was on the larger circle. The small circle was called an **epicycle.** Copernicus believed that the sun, not the earth, was at the center of the solar system. Scientists prefer the Copernican model because it is simpler.

The distance and size of the nearest planet and other heavenly bodies can be found by using **protractors** and **similar triangles.** The distance of the farther planets and of the stars can be found by measuring their amount of **parallax.** The unit of measurement used to measure the distance to the stars is the **light-year.**

Our sun is only one star in a large group of stars called a **galaxy.** There are billions of galaxies in the universe.

Checklist of Science Words

Here are some science words you read about in this unit. Can you tell what you have learned about each one?

epicycle	light-year	Ptolemaic model
galaxy	parallax	solar system

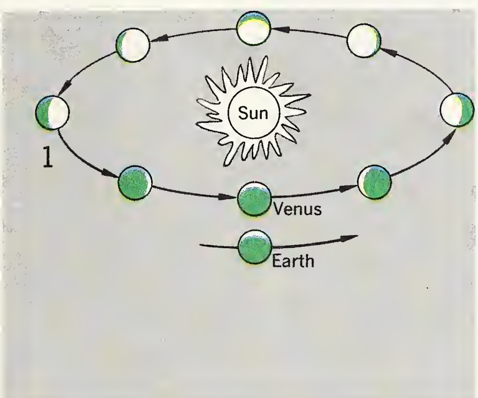
Complete the Sentence

Write the numbers 1 to 7 in your notebook. Next to each number write the answer that best completes the sentence.

1. The backward shift in position of a planet is called ___?___ ___?___.
2. The apparent motion of an object when viewed from two different points is called ___?___.
3. The size of an angle is measured with a ___?___.
4. The distance across a planet through its center is called the ___?___.
5. Distances beyond our solar system are measured in ___?___.
6. A large group of stars is called a ___?___.
7. The sun-centered model of the universe was devised by ___?___.

Can You Tell?

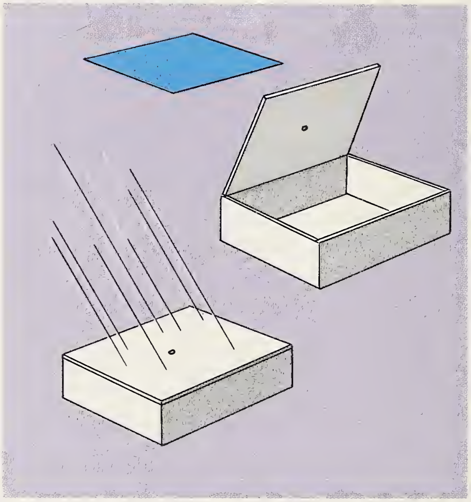
Look at the drawing below and tell why our view of Venus is constantly changing.



YOU CAN LEARN MORE ABOUT

Astronomy

You Can Make a Blueprint of the Sun's Path



Place a piece of blueprint paper in the bottom of a cigar box. Close the box. Make a small pinhole in the top. Place the box in sunshine for about six hours. Then take the box out of the sunlight and remove the blueprint. Place it in water to which you added a teaspoonful of potassium dichromate. You can buy potassium dichromate in a photography supply store. When your blueprint is developed, you will have a long arc showing how the sun moved across the sky.

You Can Visit an Observatory

These are some observatories in the United States:

Lowell Observatory
Flagstaff, Ariz.

Lick Observatory
Mt. Hamilton, Calif.

Mount Palomar Observatory
Mount Palomar, Calif.

Mount Wilson Observatory
Mount Wilson, Calif.

U. S. Naval Observatory
Washington, D.C.

Harvard College Observatory
Cambridge, Mass.

Princeton Observatory
Princeton, N.J.

McDonald Observatory
Mount Locke, Texas

Leander McCormick Observatory
Charlottesville, Va.

Yerkes Observatory
Williams Bay, Wisc.

You Can Visit a Planetarium

These are cities that have large planetariums that you can visit.

New York, N.Y.
American Museum-Hayden Planetarium

Chapel Hill, N.C.
Morehead Planetarium

Chicago, Ill.
Adler Planetarium

Colorado Springs, Colo.
U.S. Air Force Academy Planetarium

Boston, Mass.
Hayden Planetarium

Los Angeles, Calif.
Griffith Observatory and Planetarium

San Francisco, Calif.
Morrison Planetarium

Flint, Mich.
Longway Planetarium

Philadelphia, Pa.
Fels Planetarium

You Can Read

1. *Experiments in Sky Watching,* by Franklyn M. Branley. Directions for making astronomical devices and for doing experiments are included.
2. *Fun with Astronomy,* by Mae and Ira Freeman. Many experiments and projects are suggested.
3. *Worlds in the Sky,* by Carroll L. and Mildred A. Fenton. About the earth, the solar system, the stars, and the universe in general.
4. *Exploring the Universe,* by Roy A. Gallant. A history of astronomy.
5. *The Sky Observer's Guide,* by Newton and Margaret Mayall and Jerome Wyckoff. Many charts, tables, and illustrations.

6

The Nature of Light

How Light Behaves

How Light Is Reflected

Light in Different Substances

The Wave Idea of Light

In a dark room, shine a flashlight on a wall. Now put a book in front of the flashlight. What happens? You have just learned two facts about light: light travels, and light does not pass through certain materials. It is easy to observe the ways that light behaves, but it is not so easy to explain them.

How Light Behaves

Scientists have been trying to explain the behavior of light for many centuries. As more is learned about light, earlier explanations are given up because they do not fit the facts.

In this unit you will learn, in part, how today's scientists explain light. You will also learn why scientists are still searching for more complete explanations of some of the behaviors of light. When you complete the unit, you should understand how scientists develop theories about things they observe and how they test these theories.

It is difficult to describe light. You cannot take light in your hand and examine it. Light can be described only by its actions. Yet scientists have ideas about what light is, and they can test these ideas. How do today's scientists explain light?

One idea is that light is made up of tiny particles that move very rapidly, like bullets shot from a machine gun. These "bullets" are shot from a source of light, such as the sun or a candle flame. Isaac Newton developed the **particle theory of light** in the late 1600's. He called the light particles **corpuscles** (KOR-puss-'lz).

Let us test the particle, or corpuscle, idea to see how well it explains light and how light acts.

Light Can Travel Through Empty Space

Look carefully at the picture on page 195.

Imagine that the bulb and the screen are very far apart and that there is nothing between them—not even air. The bulb is turned on. Light is on its way from the bulb to the screen. Until the light reaches the screen, nothing can be seen. When the light strikes the screen, the screen will bounce, or reflect, the light into your eyes. Only then will you know that there is light.

How does what is happening in the picture explain how you are able to see the sky?

The same thing happens when the sky is lit up during the day. Here the source of light is the sun. Sunlight travels through space. When it strikes the air that surrounds the earth, you see the "sky."

On clear nights, light from the stars reaches your eyes after traveling through millions of miles of space. The light from some very distant stars will not reach the earth for years.

Does the particle idea of light explain how light travels in empty space? You can test this idea by comparing the way light travels with the way sound travels.

If you are near a wall and someone on the other side taps it, you will hear the tap. The wall carries the sound. If you put your ear to a table top, you can hear the ticking of a watch on the opposite end of the table. The table carries the sound. If you ring a bell, a person across the room can hear it. What carries the sound this time?

If you hang the ringing bell in a jar from which some of the air has been pumped out, the bell will not sound as loud. If all the air is pumped out, the ringing bell will not be heard at all. Do you remember the name of the English scientist who first did this experiment? He showed that sound must be carried through a substance. Sound cannot travel through empty space.

Sound travels in waves, and waves change the substance through which they travel. They cause the substance to vibrate, or move with a back-and-forth motion. Therefore, when we talk about sound waves' traveling, we are really talking about something that is happening to a substance. But light does not depend on something through which to travel; it can travel through empty space. Particles do not need a substance through which to travel. The particle idea of light explains why light can travel through empty space.

Light Usually Travels in Straight Lines

When an object casts a shadow, it blocks out the light from the area in shadow because light travels in fairly *straight* lines.

You can demonstrate how shadows result from the straight-line motion of light. Since you cannot use real light particles, you can use other particles, such as marbles, to help you understand the behavior of light.

EXPERIMENT

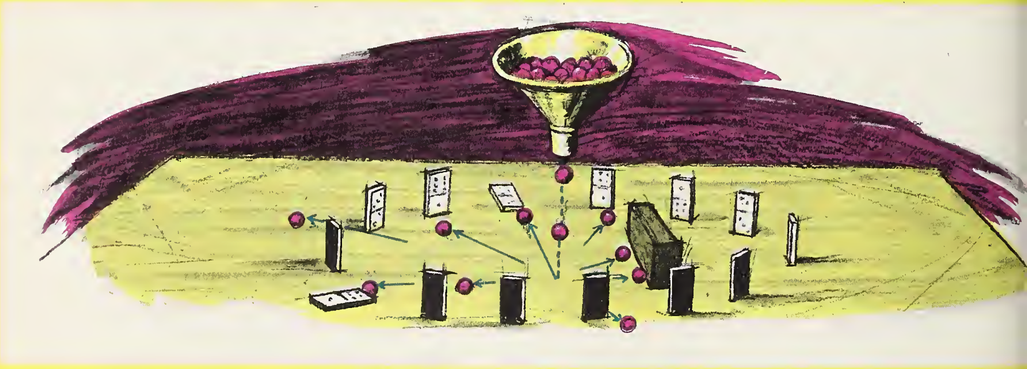
How Does the Straight-Line Motion of Light Produce Shadows?

What You Will Need

large funnel	40 marbles	smooth, level table
14 dominoes	large brick	or floor

How You Can Find Out

1. Set up the dominoes in a small ring.
2. Place the brick to one side of the center, as shown in the picture.
3. Drop the marbles from the funnel into the center of the ring.



Questions to Think About

1. Which dominoes remain standing?
2. Can you explain why they remain standing?

The marbles act like particles of light. They move in straight lines. The brick casts a kind of "shadow." The marbles cannot strike the dominoes that are shielded by the brick.

Now think of an explosion of tiny particles, such as the one in the picture. After the explosion, each particle travels at a high speed. A person standing in front of a wall would block or absorb some of the particles. The particles reach every part of the wall except the part that is blocked by the person. That part is dark. Because the particles travel in straight lines, they cannot reach that part of the wall. A shadow of the person blocking the particles of light is formed on the wall. The particle theory of light, then, explains the fact that shadows are formed.

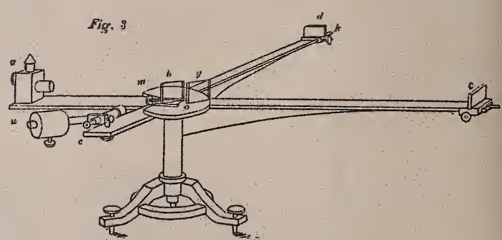
Albert A. Michelson

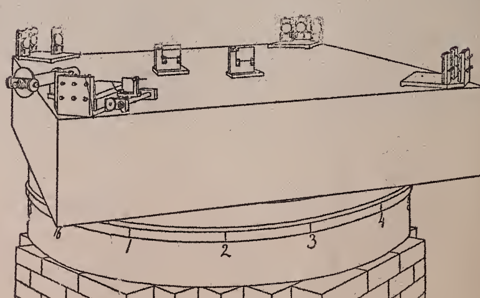
(1852–1931) United States

If you want to measure something in inches, you use a ruler. If you want to weigh yourself, you step on a scale. But how would you measure the speed of light? Light travels 186,000 miles per *second.* This speed means light could travel eight times around the earth at the equator in the time it takes you to snap your fingers twice.

Why is it important to measure the speed of light? When scientists observe the stars, they want to know how far away the stars are. To know this, the scientists must know how long it takes for the starlight to reach the earth. The distance that light travels in one year is called a light-year. A light-year is the unit of measurement scientists use to measure distances in the universe. The more accurately they know the speed of light, the more accurately they can measure the universe.

In 1868, when Albert Michelson was sixteen years old, he entered the United States Naval Academy at Annapolis to become a naval officer. Two years after he graduated, he became an instructor there. He read that two famous French scientists had measured the speed of light very accurately. Michelson became interested in their experiments and built





a machine like the one the Frenchmen used. He spent $10.00 of his own money to do this. To his astonishment, Michelson was able to measure the speed of light even more accurately than the two famous scientists had measured it.

Michelson decided to become a scientist. He resigned from the U. S. Navy and went to Germany, where he studied physics. He later invented machines that could measure in millionths of an inch. He also discovered a way to measure the size of a star. But his most famous accomplishment was to measure the speed of light more precisely than anyone had before.

The pictures on page 198 show the machines he designed to do this. The wheel with the eight mirrors reflects a flash of light to a mirror on a mountaintop 23 miles away. If the wheel is turning at the correct speed, the flash of light will be reflected back into the eye of the observer from another mirror. This will happen only when the wheel is turning at one particular speed. Knowing how fast the wheel is turning, Michelson was able to calculate how fast the flash of light traveled. For his accomplishment, he was awarded the Nobel Prize for physics in 1907. Albert Michelson was the first American to receive this distinguished award.

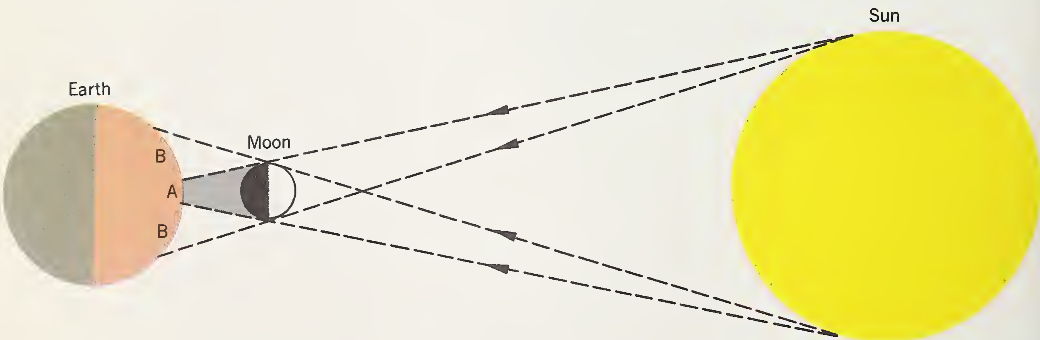
Using What You Have Learned

1. Find out about the speed of light. Look for answers to these questions:

a. At what speeds does light travel in various substances?
b. How does the speed of light compare with the speed of sound?
c. How do scientists use the unit of measurement called the light-year?

2. Find out about sources of light. What things, besides the sun, are natural sources of light? What has man used as sources of light?

3. On the basis of what you have read about shadows and the way light travels, explain what happens during an eclipse of the sun. Study the picture on this page. From where do you think the sun would not be seen at all? From where would only part of the sun be seen?



1. In area of total shadow (A)
2. In area of partial shadow (B)

How Light Is Reflected

The ways light is *reflected* is a key property of light.

What happens when a ball hits a surface? It bounces back. The same thing happens to light. When light particles strike an object, they bounce back from it. We say that they are *reflected*. Light particles reflected from

OBSERVATION

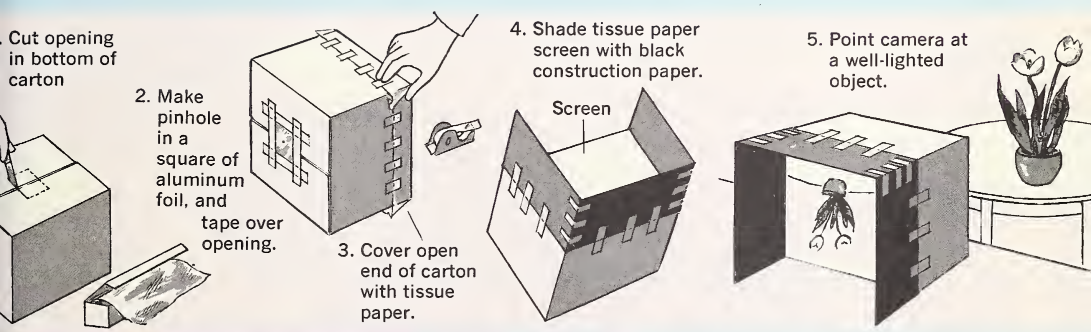
How Is an Image of an Object or Scene Formed?

What You Will Need

pinhole camera tissue-paper screen

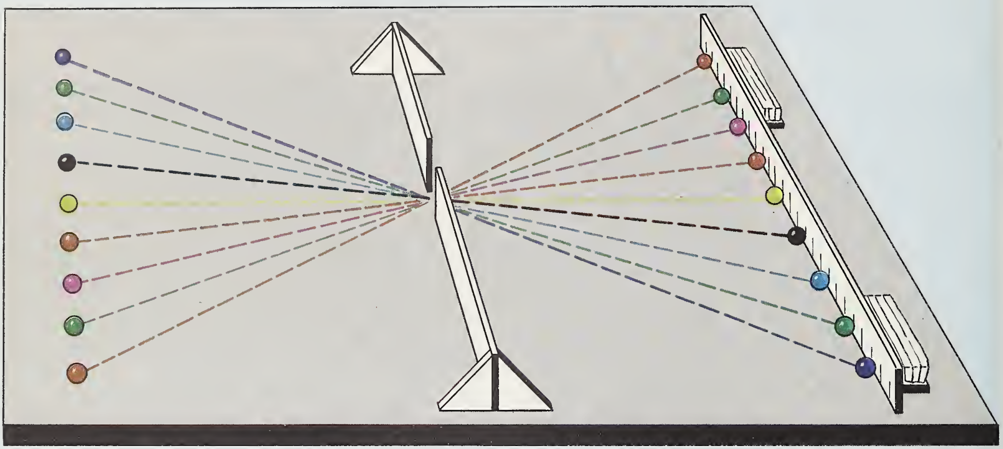
How You Can Find Out

1. Follow the directions for making a pinhole camera shown below.
2. Darken the room.
3. Place the camera so that the pinhole faces the window.
4. Look at the image formed on the tissue-paper screen.



Questions to Think About

1. What do you notice about the image?
2. Why is the pinhole camera image not very bright?



an object form an image of the object on another surface. That is how we see things. Light reflected from an object enters our eyes through the pupils. An image of the object is formed on the *retina,* which is located on the rear inner wall of the eye. The retina acts as a screen. When nerve messages from the retina reach the brain, we see the object. Find out more about the retina and the images formed on it.

The particle idea of light, which represents light as particles traveling in straight lines, can be used to explain the upside-down image in the pinhole camera. Imagine a row of marbles set up in front of a ridge, as in the picture above. The opening in the ridge is just big enough to let one marble through. Now suppose that the marbles were shot through the opening. The marbles would land against the

yardstick on the other side of the ridge.

Study the picture again. Because each marble travels in a straight line, the one at the top of the row goes through the opening and ends up at the 32-inch mark on the yardstick. The sixth marble in line ends up at the 14-inch mark. The bottom marble in line ends up at the 2-inch mark. Looking at the positions the marbles take, can you explain the upside-down image?

Mirror Images

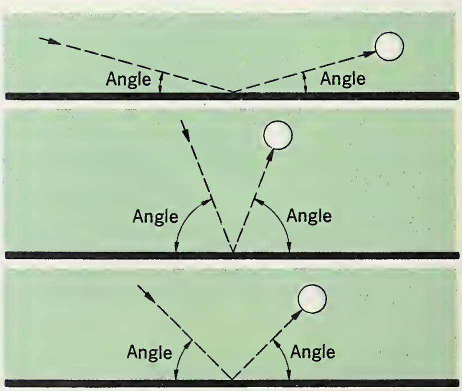
A mirror reflects light so well that it shows clear images of objects. What things besides mirrors show images? Now think of some things that do *not* reflect light well enough to show images. What do you think is the difference between the two groups of things?

Can you show the difference in reflections given by smooth and rough surfaces? Several ping-pong balls, a shallow box of gravel, and a smooth table are needed.

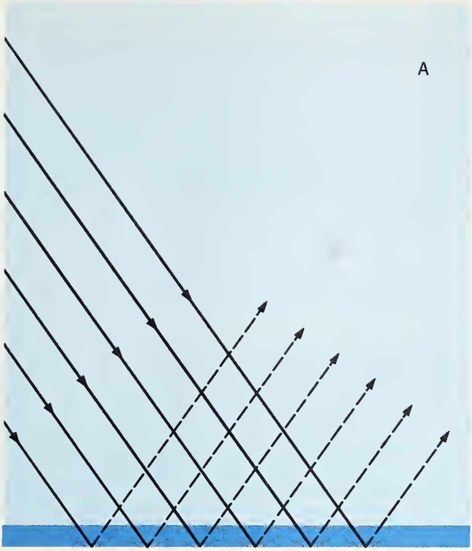
Have a friend stand at the opposite end of the table. Bounce the ping-pong balls toward him, one at a time. Now substitute the shallow box of gravel for the smooth table. Bounce the ping-pong balls against this surface. Could your friend easily catch the balls you threw on the table? Did it become more difficult to catch them when the surface changed?

Now stand to the side and observe while your friend throws the balls on the smooth table. Ask him to throw the balls at different angles. Notice how each one bounces off. If you

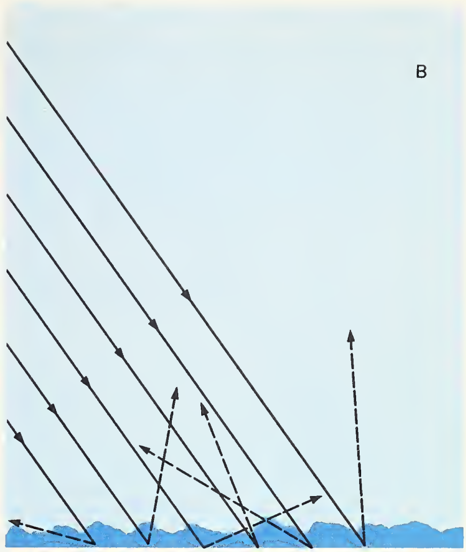
could measure the angles, you would find that the angle at which each ball bounces off is equal to the angle at which it is thrown. Study the diagrams on the bottom of this page to see this fact illustrated.



How would you go about measuring the angles? What do you find in each case?



Regular reflection



Irregular reflection

How do the light particles bounce off each of the surfaces shown above?

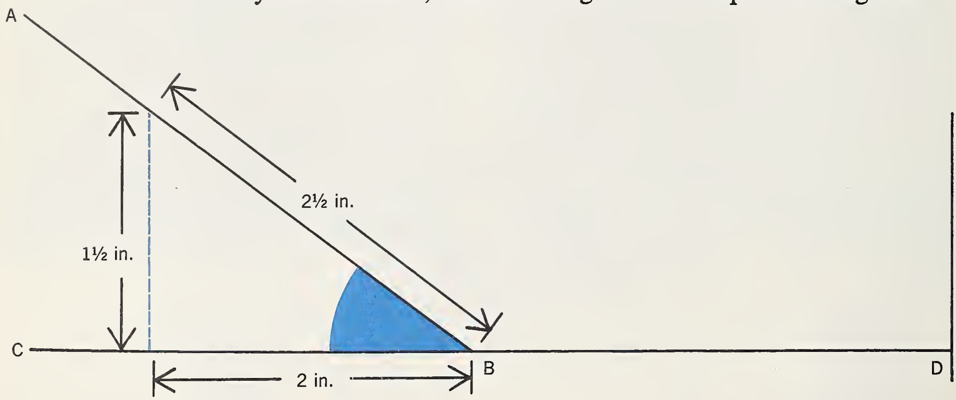
Light particles are like the ping-pong balls. The angle at which a light particle bounces off a surface is equal to the angle at which it hits the surface. When light particles strike a very smooth surface, they are reflected evenly, as shown in figure A, and a clear image is formed. When light particles strike a rough surface, they are reflected in many directions, as shown in figure B. The light is scattered, and a clear image is not formed. Remember that light particles are very tiny. A roughness that you could hardly feel might be very big in comparison to a light particle. As you know, most surfaces do not reflect images.

You have learned that when a shiny surface reflects light to your eyes, all the light that reaches your eyes is reflected from the same spot on the shiny surface. Look at figure A. Compare the angle at which the light strikes the surface with the angle at which it is reflected. Why do no other spots on the smooth surface reflect light to your eyes?

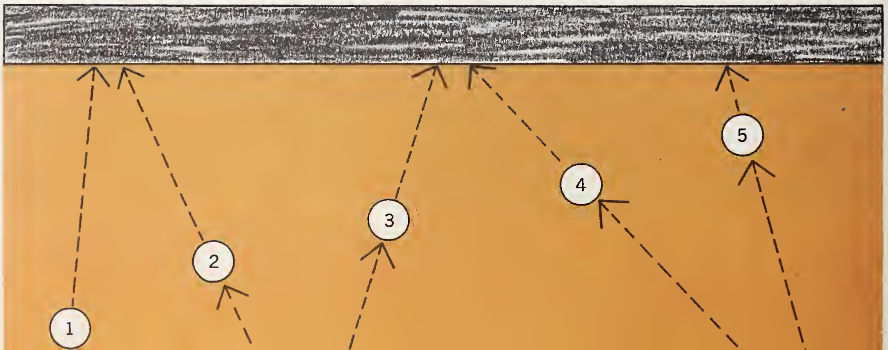
Now look at figure B. Why, when a lamp lights a rough surface such as blotting paper, does the entire surface seem to be fairly evenly lighted?

Using What You Have Learned

1. In the diagram below, the line from **A** to **B** meets the line from **C** to **D** at an angle. Let us call it Angle **B.** If you had no way of measuring Angle **B**, how could you draw another angle equal to it? (Hint: How do you think the angles of two matching triangles compare with each other?) In your notebook, draw an angle that is equal to Angle **B.**



2. John rolled five balls to a wall. Each time he stood in a different place. The floor was perfectly smooth. The drawing shows the path of each ball and the spot where it hit the wall. On a separate sheet of paper, copy the drawing exactly. Now, on your drawing, show the path each ball took as it rolled away from the wall. (Do not draw in this book.) How is the behavior of each ball like the behavior of a particle of light?

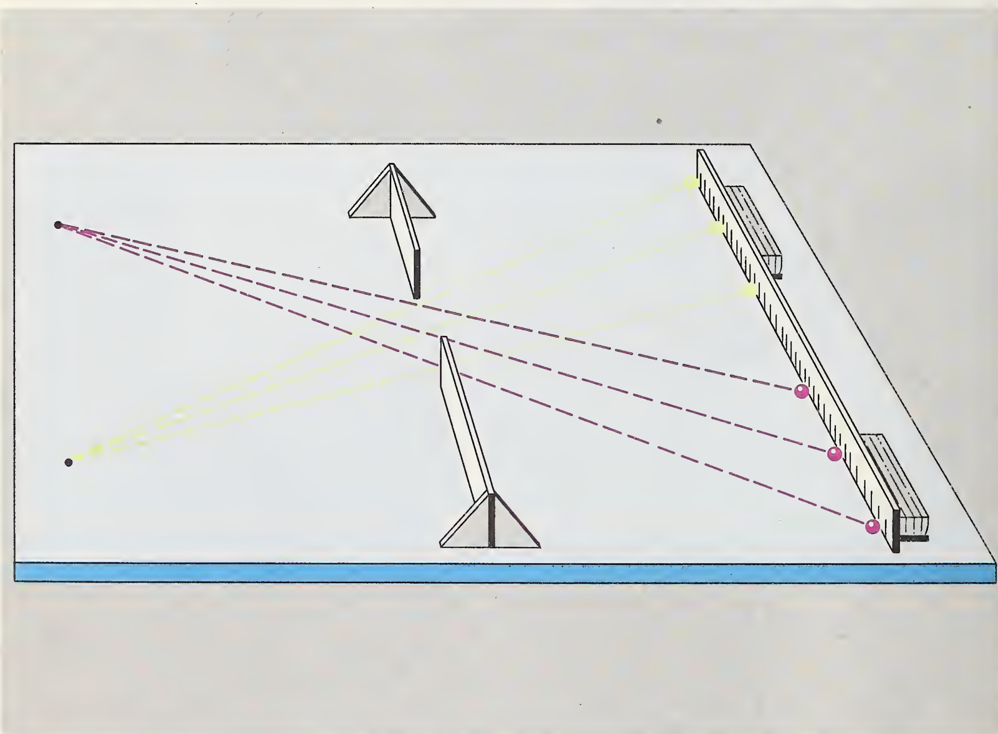


3. Have someone stand at the front of the classroom and hold a mirror straight up and down. (Or, if you can, mount a mirror flush against a wall at eye level.) Ask one person in the class to name an object he sees in the mirror. Stretch a string from that person's position to the mirror and from the mirror to the object he sees. Examine the angles at which the string comes to and goes away from the mirror. Repeat this activity with two more people. What does this show?

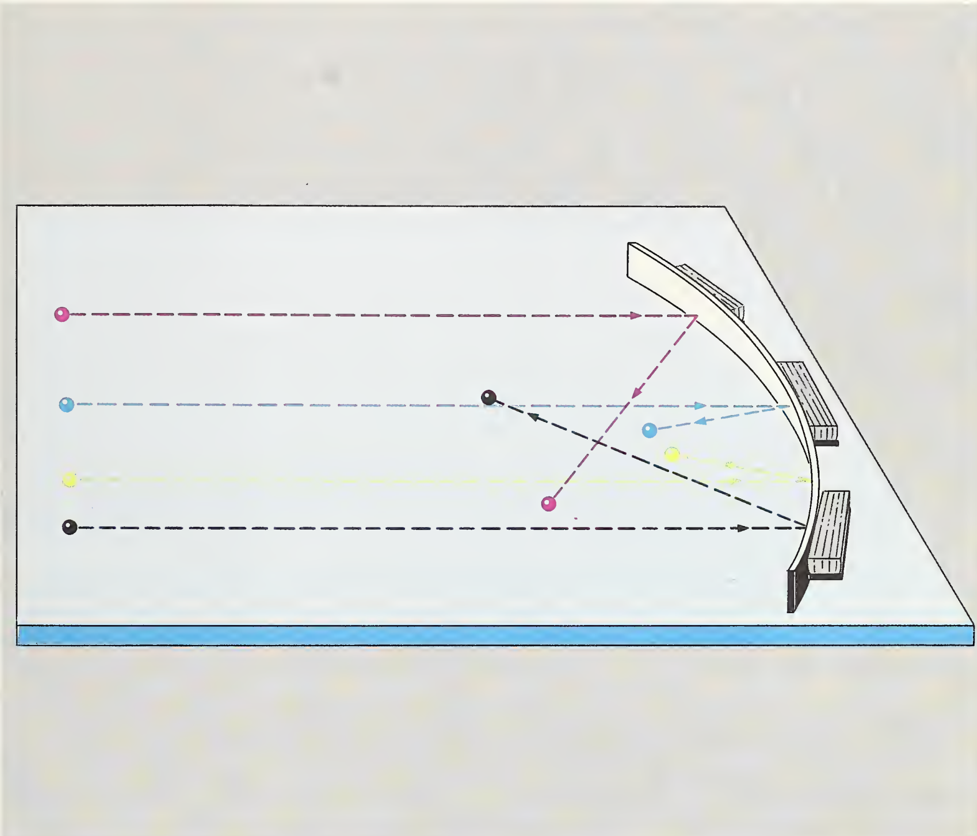
4. A pinhole camera with a tiny hole to let in light will form a distinct, but not bright, image. Make a camera with a hole larger than the one in the camera that you made before (page 201). Notice what happens to the image.

To understand the results better, imagine that you are shooting marbles through an opening in a ridge such as the one described on page 202. This time, however, the opening is about three times as big. Imagine shooting several marbles from the same spot. Would they all land at the same spot on the yardstick on the other side of the ridge?

In your pinhole camera, the spreading of light particles that come from the same spot results in fuzziness.



5. Find out in what ways a photographic camera is like the pinhole camera that you made. Find out in what ways it is different.



6. The particle idea of light can be used to explain the behavior of light in an auto headlight, which has a curved reflector behind the light bulb. Roll marbles straight against a curved surface as shown in the picture. What do you observe?

Light in Different Substances

Light travels at different speeds in different substances. It travels fastest in empty space. It travels faster in air than in water or glass. You can use marbles, water, and molasses to experiment and find out whether or not objects move at different speeds through different substances.

EXPERIMENT

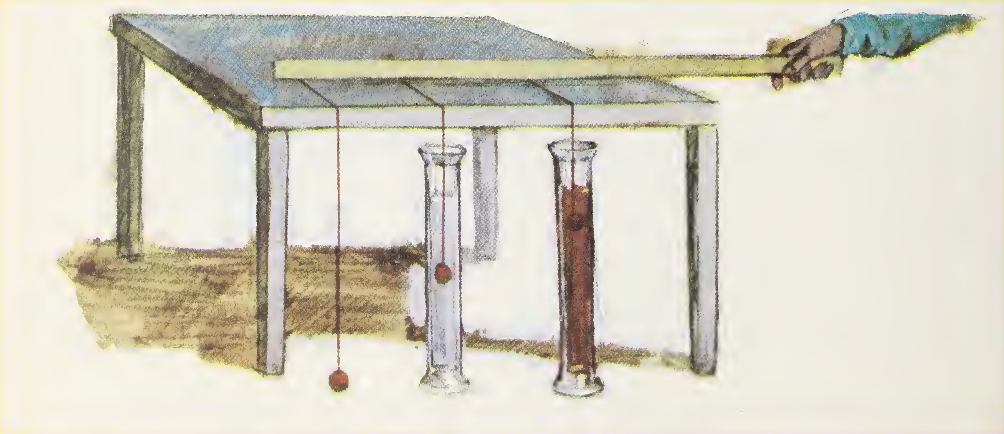
Do Objects Move at Different Speeds Through Different Substances?

What You Will Need

tall jar of water   marble   tall jar of molasses

How You Can Find Out

1. Drop a marble to the floor. Note its speed.
2. Drop it into the water. Drop it into the molasses.



Questions to Think About

1. How does the speed in air compare with that in water?
2. How fast does the marble move in molasses compared with its speed in air and water?

Particles of light, like the marbles, may travel at different speeds through different substances. Therefore, the speed of light particles may be changed by a change in the substance through which they are traveling. They may speed up or slow down as they pass from one substance into another.

OBSERVATION

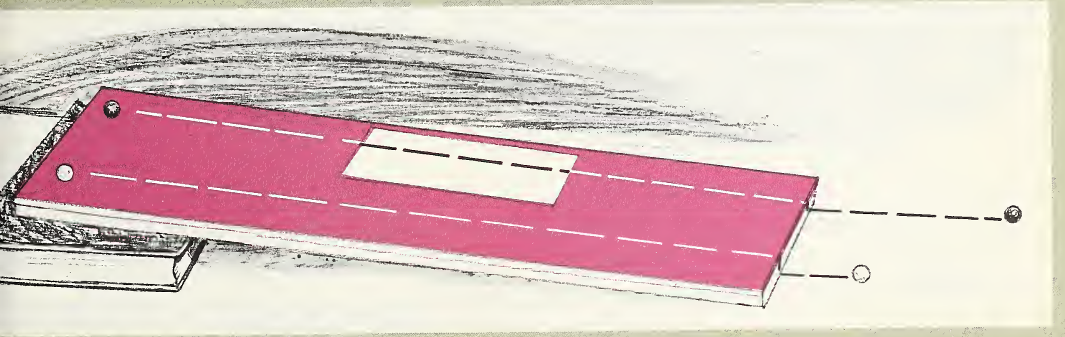
Why Does a Pencil in a Glass of Water Appear Broken?

What You Will Need

marbles	felt pad
book	smooth paper

How You Can Find Out

1. Put a pencil into a glass half full of water. Record your observations.
2. Use the particle model of light to explain what you see.
3. Set up the felt pad, paper, and books as in the picture.
4. Roll the marble down the pad so that it crosses the paper.



Questions to Think About

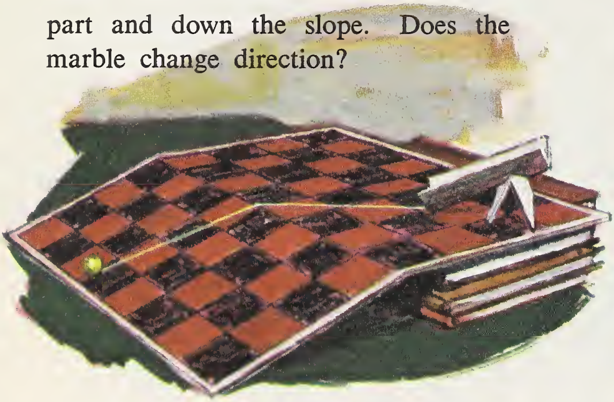
1. How does the direction of the marble change as it rolls over the paper?
2. Can you now explain why a pencil in a glass of water appears broken?

How Light Behaves When Its Speed Changes

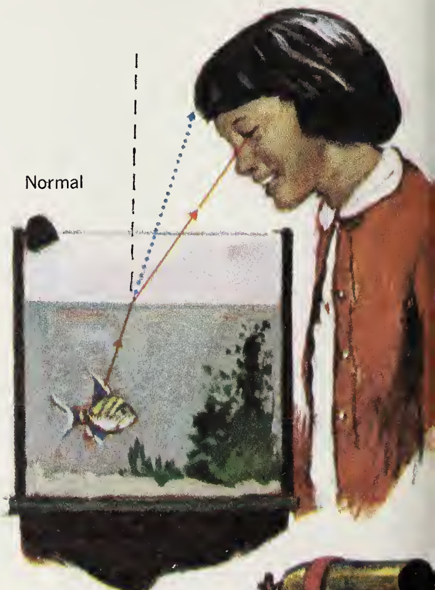
You know that light travels through different substances at different speeds. When it enters a new substance in which its speed changes, it bends. The bending is caused by the change in speed.

Try another method to show how the path of particles bends when the particles suddenly change speed.

Place one half of a checkerboard on a book. Let the other half slope down. Roll a marble across the level part and down the slope. Does the marble change direction?



In the top diagram on the right, a ray of light is shown moving at a slant from water to air. In the bottom diagram, the ray is shown moving from air to water. In each, there is a line *perpendicular* to the surface of the water where the light strikes the surface. This line is called the *normal*. The dotted lines show how the light would move if it continued in a straight line. When light moves from water to air, it bends away from the normal. When it goes from air to water, it bends toward the normal. The bending of light when it enters a different substance is called **refraction** (rih-FRAK-shun).



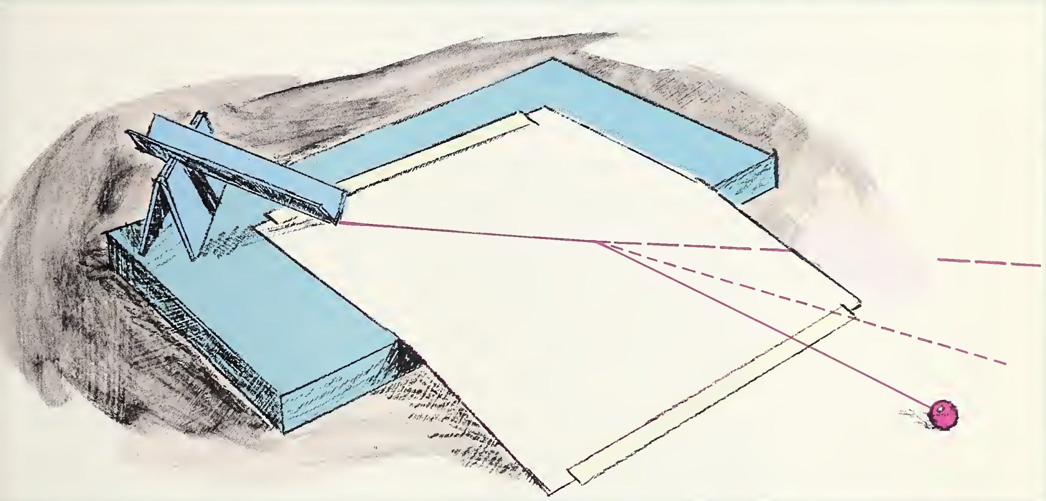
Do Fast-Moving Particles Bend Less Than Slow-Moving Ones?

What You Will Need

piece of cardboard	flat board	sheet of paper
marble	level table	tape

How You Can Find Out

1. Place the board on the table.
2. Tape the paper to the board so that the paper slopes gently to the table.
3. Fold the cardboard to make a launcher.
4. Prop up the launcher.
5. Roll a marble across the board and down the paper at various speeds. Tilt the launcher to change the speed of rolling.



Questions to Think About

1. How does the direction of the path across the paper change each time the speed of the marble is changed?
2. Make up another experiment to prove what you have learned.

You can see that fast-moving particles bend less than slow-moving ones. A bullet, for example, goes fairly straight to its target. The refraction of light, then, depends on its speed. Light bends more when it enters substances that slow it down. Since light behaves in this way, would you expect more refraction when it goes from empty space through glass or from air through glass?

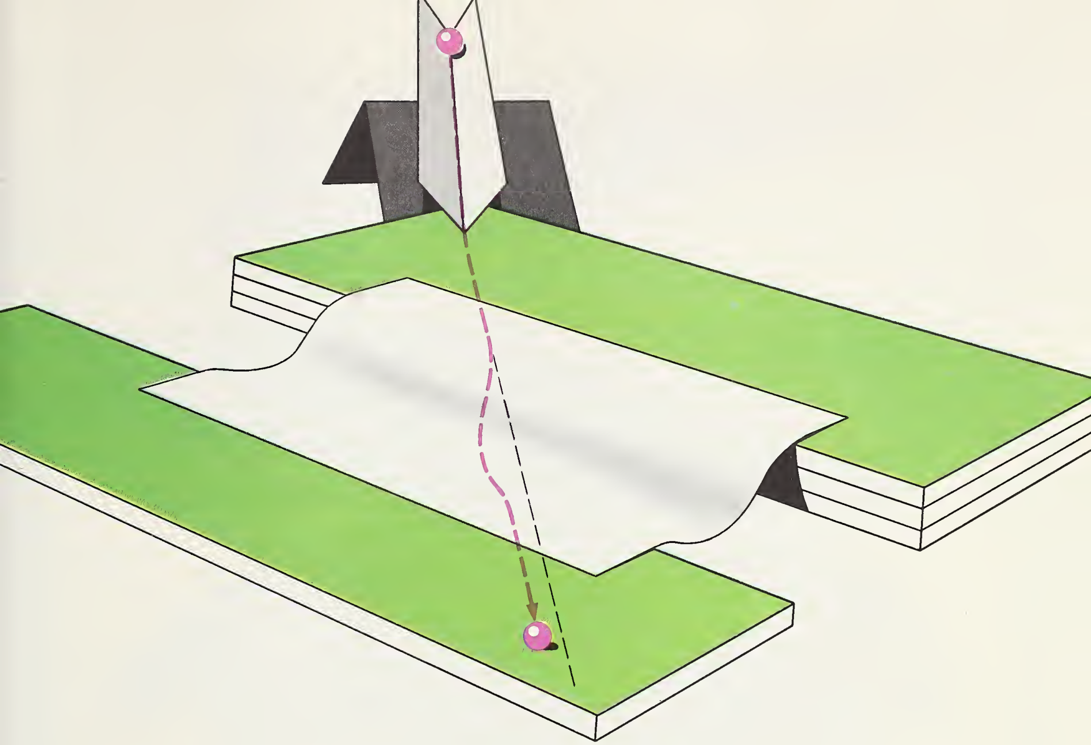
Although marbles are useful for demonstrating the particle idea of light, you must remember that marbles are not exactly like light. You could not demonstrate all the behaviors of particles of light with them. Imagine, for example, that two flashlights are turned on. The beam of one crosses the beam of the other. Each beam travels through the other as if it were not there. Now imagine two volleys of marbles crossing each other. The marbles would simply collide and scatter. You must think of light particles as being different. A light particle does not have a shape as definite as that of a marble.

Using What You Have Learned

1. Pictured on the next page is another way to study the bending of a particle's path. Tape a smooth piece of paper between two pads or long boards so that it forms a trough. One pad or board should be about two inches higher than the other. Make a launcher and prop it up. Roll marbles across the trough from your launcher. Roll them from the higher board to the lower. Roll them at different angles. See how the direction changes each time.

2. Astronomers know that stars are not where they seem to be unless they are directly overhead. Can you explain why stars overhead are seen in their correct positions while others are not?

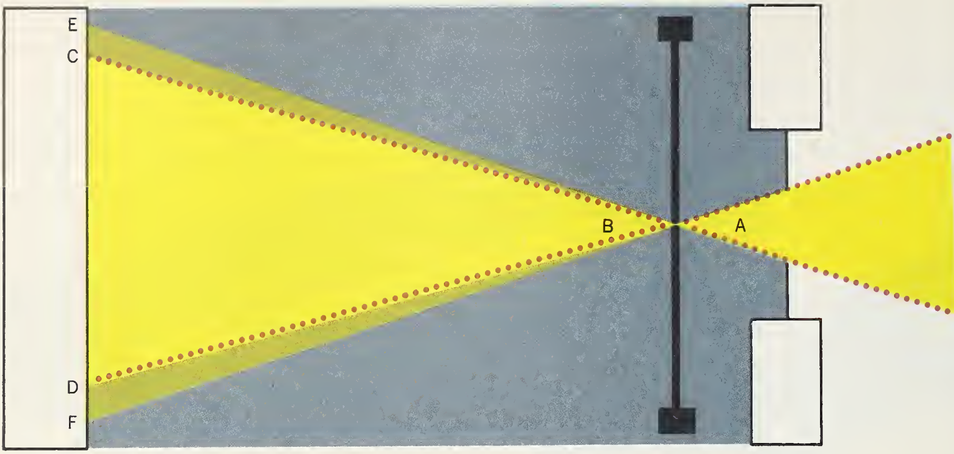
3. Sir Isaac Newton was one of the world's greatest scientists. He used the particle idea to explain many behaviors of light. Find out about Newton's explanation of refraction.



4. Make a record of the path of a particle as it passes over different substances. Set up a single board with paper sloping gently off it to the table. Put a blank sheet of white paper on the level board and another on the table where the marble rolls off the paper slope. Place a sheet of carbon paper, carbon side down, on each of the sheets. Roll a heavy marble across the papers. Pick up the carbon papers and you will find a record of the marble's path.

Roll the marble at different speeds and compare the paths.

5. Put a penny in a shallow bowl. Step back until the penny is just hidden from your view by the side of the bowl. Now let a friend pour some water into the bowl without disturbing the penny. Do not move your head. The penny will come into view. Explain what happens.



The Wave Idea of Light

Scientists have found the particle idea of light very useful. But there are some ways in which light behaves that the particle idea does not explain in a satisfactory way.

Problems Raised by the Particle Idea of Light

Imagine a beam of light entering a darkened room through a slit, shown by A in the diagram. This slit is blocked by a screen with a tiny hole in it, shown by B. The light is allowed to fall on a wall. Francesco Grimaldi (grih-MAHL-dih), an Italian scientist who lived in the 1600's, performed such an experiment. According to the particle idea, which represents light as traveling in straight lines, light should have been seen on the wall between points C and D only. Grimaldi found that light was seen as far as points E and F. He discovered that the light bent slightly as it passed the edges of the hole in the screen. The bending of light as it passes a sharp edge is called **diffraction** (dih-FRAK-shun).

Diffraction is different from refraction. Light does not pass from one substance to another. According to the particle idea, light should always travel in straight lines within a single substance. But in diffraction it bends around sharp edges.

The following activity demonstrates this behavior of light.

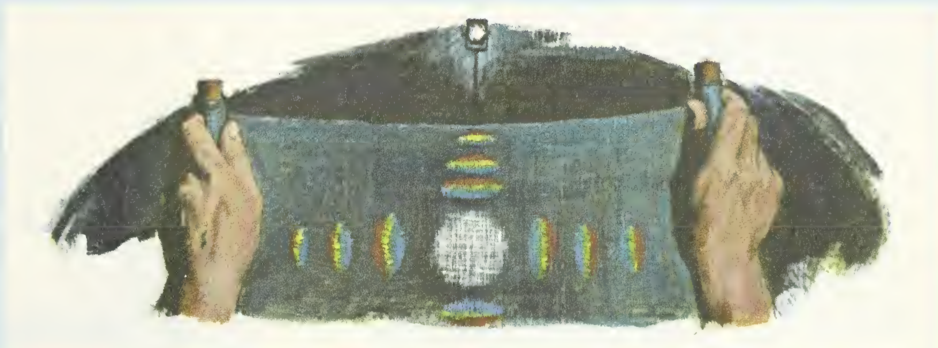
What Behavior of Light Is Not Explained by the Particle Theory?

What You Will Need

fluorescent light silk scarf

How You Can Find Out

1. Turn on the light in a far corner of a darkened room.
2. Hold the silk scarf at arm's length.
3. Look at the light through a tightly stretched section of the scarf.



Questions to Think About

1. Where is the light brightest?
2. Why doesn't the particle theory explain this behavior of light?

If light travels in a stream of particles, you would expect the light to pass in a steady stream through each tiny opening in the material. Instead, the light is brightest in the center of the scarf. Less bright patches of light extend from this center. The particle idea of light does not explain what is happening here.

The behaviors of light that cannot be explained in a satisfactory way by the particle idea have led scientists to the **wave theory of light.**

You are familiar with certain kinds of wave motion. For example, if you drop a pebble into a puddle, waves move out in all directions from the point where the pebble struck the water.

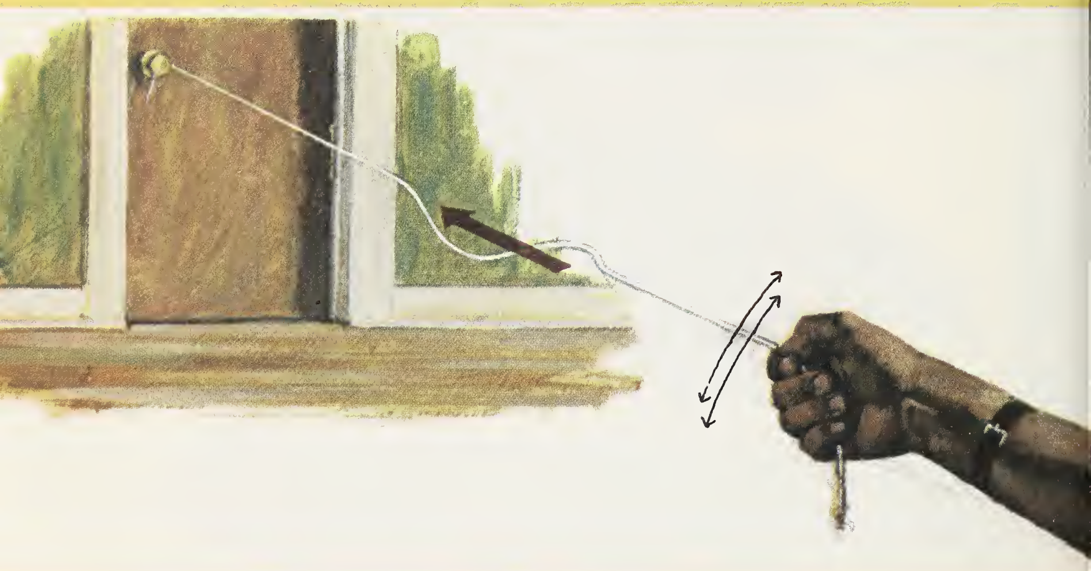
How Can You Produce Wave Motion?

What You Will Need

15-foot length of rope doorknob

How You Can Find Out

1. Tie the rope to the doorknob.
2. Hold the rope straight out, but leave a little slack.
3. Snap the rope sharply. Observe a wave travel along the rope.



Questions to Think About

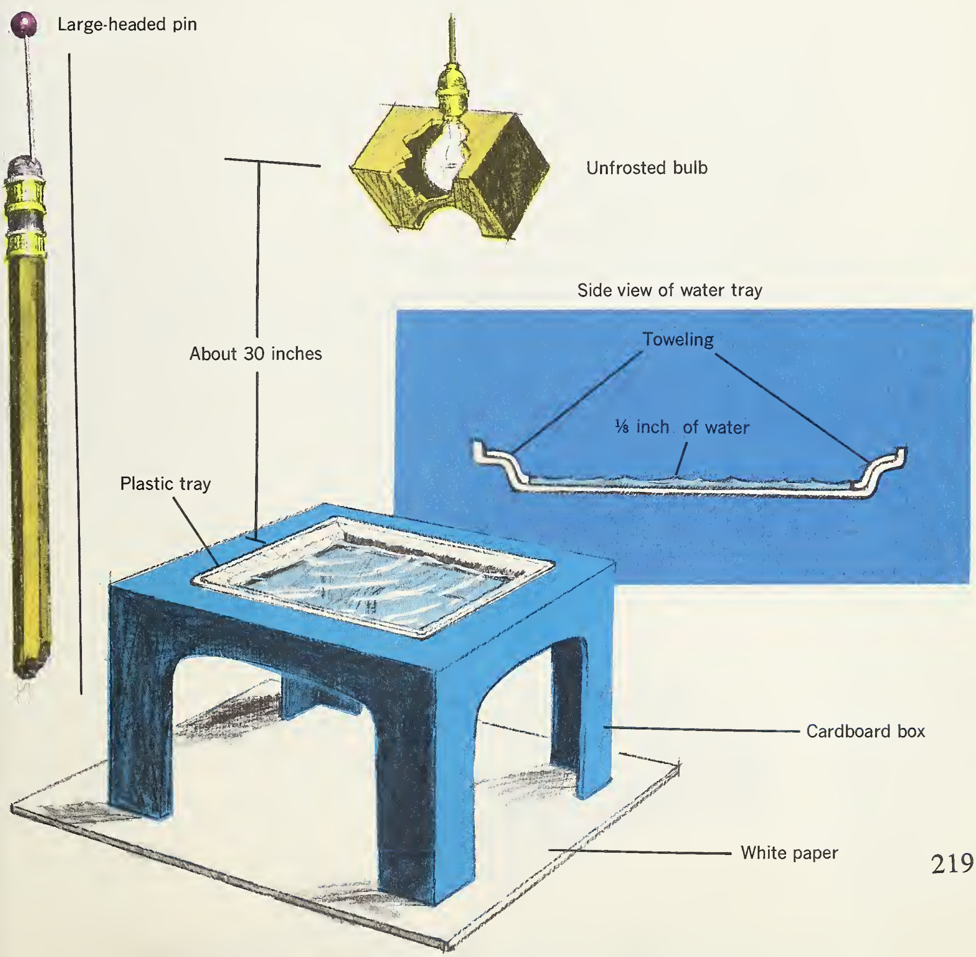
1. Did the piece of rope held between your fingers travel? What travels is a pulse of energy called a wave. After the wave stops, all the parts of the rope are in their original positions. An important characteristic of wave motion is that substances in which a wave travels do not travel with the wave.
2. Can you hypothesize how wave motion might cause light to spread when passing through a silk scarf?

According to the wave idea, light travels out in waves in all directions from its source. This idea can be used to explain what happened in the activity with the silk scarf. But first you must learn more about wave motion.

Making a Ripple Tank

In many ways the behavior of water waves is like that of all waves. To study wave motion more fully, you will need a ripple tank. You will then be able to experiment with water waves.

Study the ripple tank shown in the diagram. When the light shines through the water and the plastic tray, shadows of any waves in the water will be formed on the surface beneath the tray. Shadows can be seen more clearly on white paper than on a floor or table top.



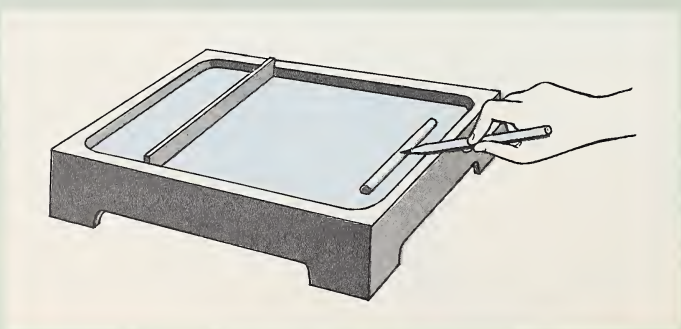
How Can Wave Motion Be Shown?

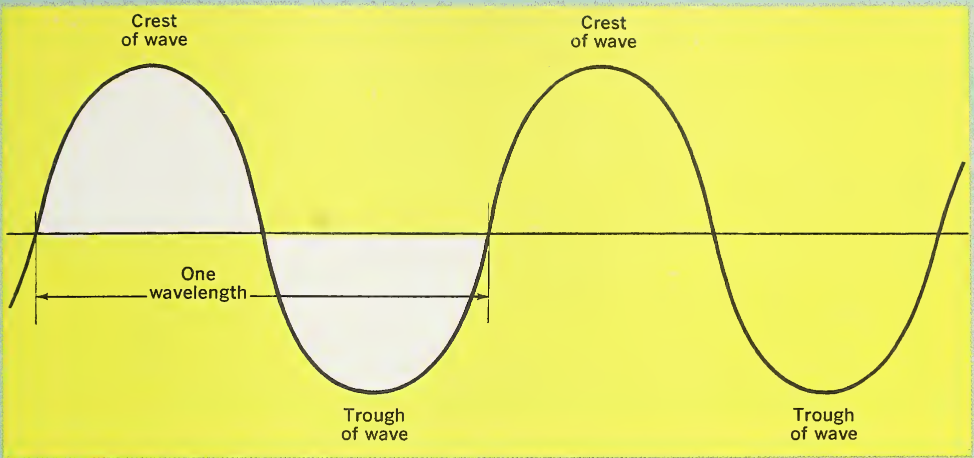
What You Will Need

large cardboard box	transparent plastic container (20″ x 10″ x 1½″)	pin
unfrosted light bulb	white paper	pencil
ruler	level table	paper towels
	water	one-inch-thick wooden dowel

How You Can Find Out

1. Cut large openings in the sides, top, and bottom of the box.
2. Spread a sheet of white paper on the table.
3. Put the box directly over the white paper.
4. Put paper towels along the edges of the plastic container.
5. Place the plastic container on top of the box.
6. Hang the light over the plastic container.
7. Fill the container with ⅛ inch of water.
8. Partially darken the room.
9. Turn on the light over the container.
10. Take the pencil with a pin stuck in the eraser and tap the water surface with the pinhead.
11. Adjust the light so that the shadows of waves show clearly on the paper.
12. Observe the wave shadows made by running your finger through the water in a straight line. This can also be done by using the dowel. Float the dowel at one end of the tank. Tap the dowel gently.





Questions to Think About

1. With the pinhead, waves move out in all directions, as light does. What form did the waves assume?
2. The **crest** is the high point of each wave. Each low point is called a **trough** (trawf). The pinhead waves move out in a circular pattern that is repeated again and again.
3. Put the edge of a ruler into the water. The ruler will disturb the water. Observe how the disturbance is passed along on the surface of the water. In what direction does it move out in relation to the ruler?

Reflection of Waves

We can use the wave idea of light to explain some of the same behaviors of light that we have explained by the particle idea. For example, we can explain reflection by using either the particle idea or the wave idea of light.

The next activity will explain how the wave model of light explains reflection. For this activity, you will use the ripple tank which you learned how to make on page 220.

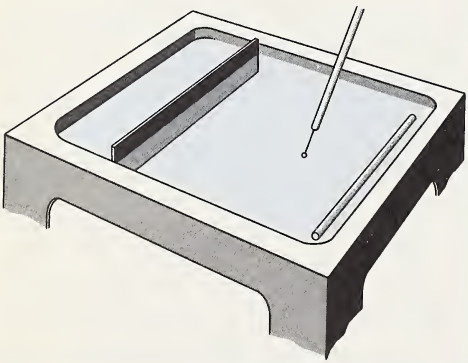
How Can the Wave Theory of Light Explain Reflection?

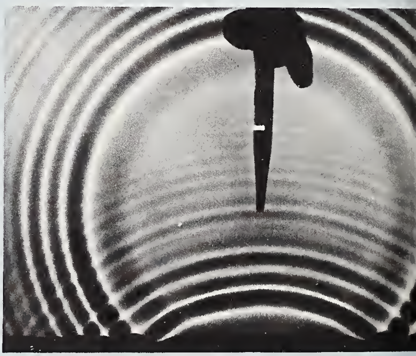
What You Will Need

ripple-tank apparatus	pinhead dowel	board (9¾″ x 2″ x ½″)

How You Can Find Out

1. Place the board across the tank, three quarters of the way from one end.
2. Produce circular waves with the pinhead.
3. Then produce straight waves with the dowel.
4. Observe what happens to these waves as they strike the obstacle.





Questions to Think About

1. How is the reflection of the straight pulse (made by the dowel) different from that of the circular pulse (made by the pinhead)?
2. How does the wave idea explain how light is reflected?

Refraction of Waves

Refraction, too, can be explained by the wave idea. The speed of a water wave depends on the depth of the water. Therefore, if you could change the depth in a section of your tank, you could make the waves change their speed.

Place a sheet of glass 10″ x 3″ in one section of the ripple tank. Produce waves with the dowel. Notice the waves that are made.

What happens to the waves as they pass over the glass? Why? Since light changes its speed as it goes from one substance to another, light waves are bent, or refracted, as they travel from air to water.

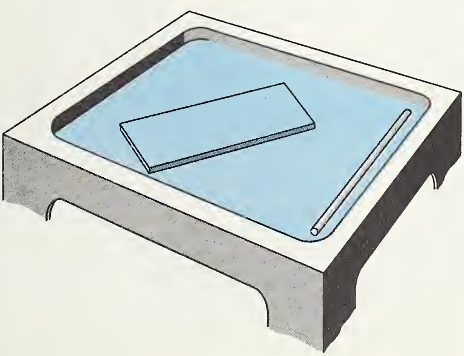
Crossing Beams of Light

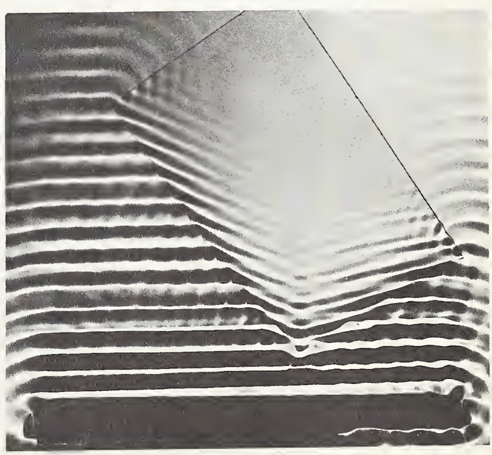
We discussed earlier what happens when we shine two flashlight beams across each other. Each beam travels through the other as though it were not there. We had some trouble explaining this behavior by the particle idea. Perhaps the wave idea fits this behavior better.

Waves can pass through each other without disturbing one another. Therefore the crossing of waves seems to be a better explanation than the crossing of streams of particles.

Diffraction of Waves

What happens in diffraction, or the bending of light as it passes a sharp edge? This bending is different from refraction. In refraction, the light, which is traveling in a straight line, bends to form an angle. The bending in diffraction might be described as a gentle curve. The particle idea, you remember, did not explain this behavior. According to the particle idea, what would you expect to happen when light passes a sharp edge?





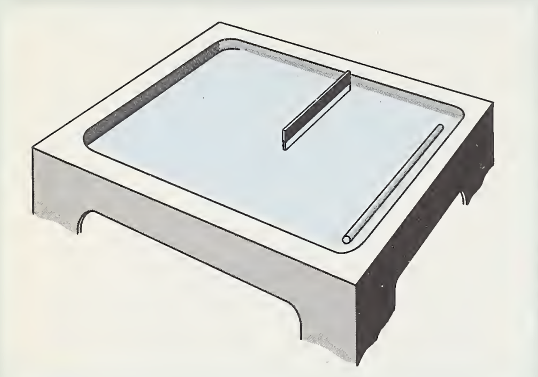
How Do Water Waves Behave When They Pass a Sharp Edge?

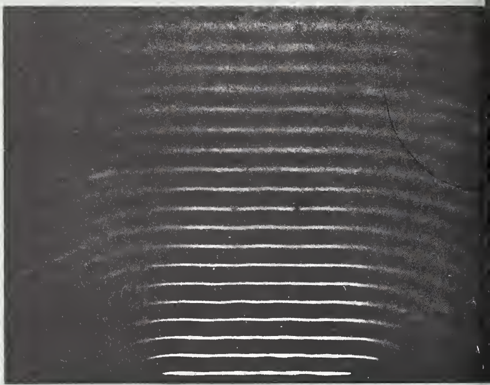
What You Will Need

ripple tank ruler wooden dowel

How You Can Find Out

1. Place the ruler in the tank.
2. Use the dowel to produce a wave.





Questions to Think About

1. What happens to the wave as it passes the edge of the ruler? The speed did not change, since the depth of the water was not changed. The change that did occur was due to diffraction, not refraction. In diffraction the waves do not bend so sharply. Light waves are also diffracted after passing a sharp edge.
2. Look against the picture on page 216 and the description of Francesco Grimaldi's experiment on page 216. Can you explain now what Grimaldi observed?

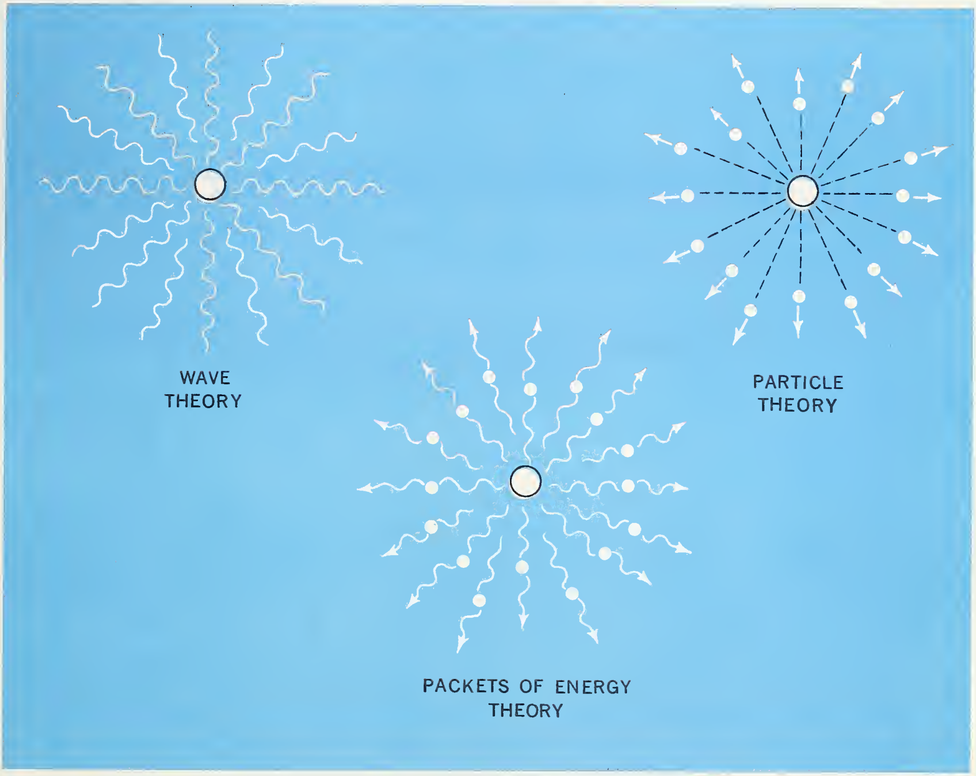
Wave Theory or Particle Theory?

Diffraction, then, is one behavior of light that can be explained by the wave idea and not by the particle idea. The wave idea is useful, too, in explaining other behaviors that you will learn about later on in your study of light. But it does not explain all the behaviors of light.

Both the particle idea and the wave idea are useful, but neither by itself is entirely satisfactory.

Today, scientists think that the most satisfactory explanation is a combination of both. They think of light as little packets of energy behaving like waves. As you go on in science, you will learn more about these packets of energy and how they move from place to place in a wave motion.

Is light a kind of wave motion, as shown on the left, or is it particles in motion, as on the right? Scientists think it may be a combination of both, as in the center.



Using What You Have Learned

1. Show that the substance in which a wave travels does not move along with the wave. Put about two inches of water in a large basin. Float small pieces of cork or balsa wood in the basin. Drop a marble or pebble in the exact center of the basin and observe the wave motion and the effect on the bits of cork or balsa. From what point do the waves move out? Do the pieces of cork or balsa move along the surface? How do they move?

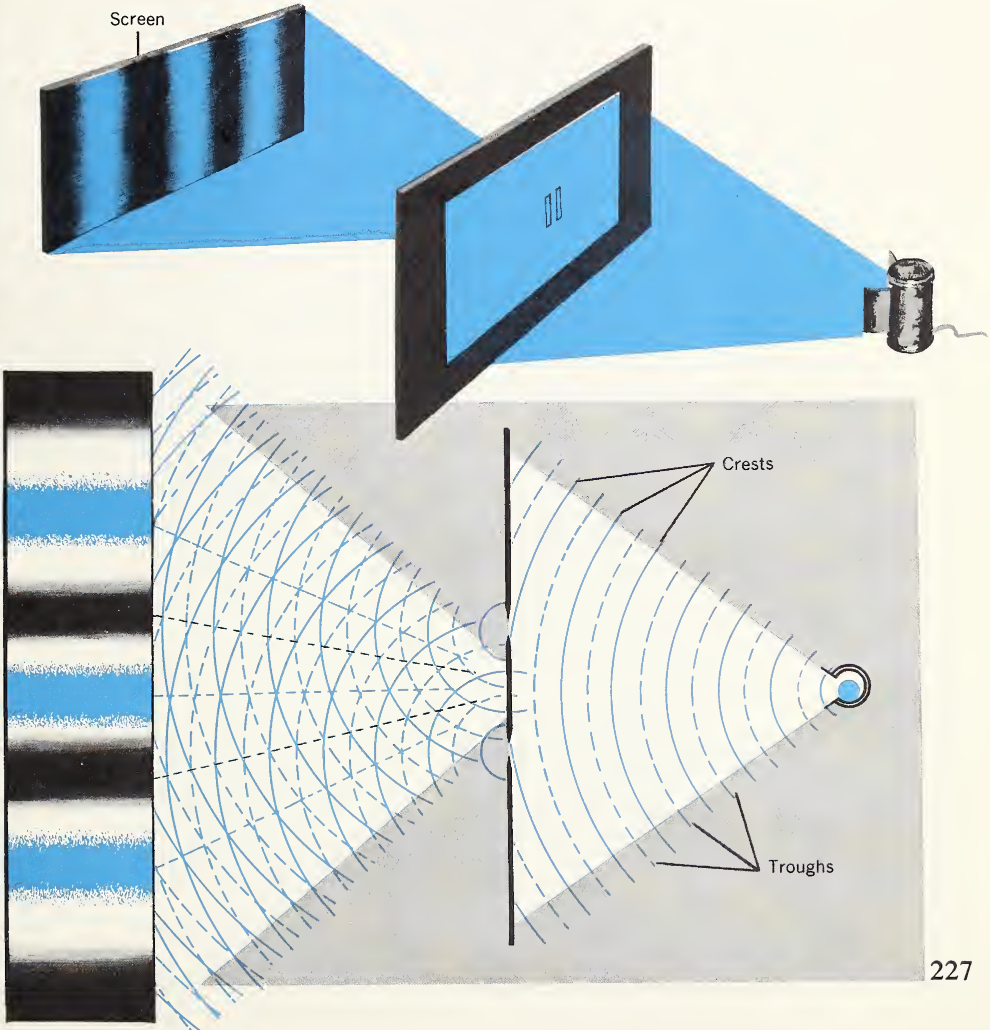
2. Here is another way to show that waves do not carry along the substance in which they travel. Line up ten marbles between two rulers as you see in the diagram. Shoot a marble against the first marble in line. What happens?

3. After the sun has sunk below the horizon, we can still see it for a few minutes. Can you explain why?

4. Find out about Thomas Young and Christian Huygens. Read about some of their important scientific discoveries.

5. Sir Isaac Newton did a famous experiment to show that white light is made up of many colors and that light of a single color is not. Find out about this experiment.

6. Imagine that light from a single source is permitted to enter through two slits as shown in the upper section of the diagram below. What would you expect to appear on the screen according to the particle theory of light? The screen shows what actually does happen. The lower part of the drawing shows how the wave theory explains what happens. Can you explain the diagram?



WHAT YOU KNOW ABOUT

The Nature of Light

What You Have Learned

There are two different theories used to explain the nature of light. These are the **particle theory** and the **wave theory.** Neither theory alone completely explains the behavior of light. The most satisfactory explanation is a combination of both theories.

The particle theory of light says that light consists of tiny particles of energy called **corpuscles.** The wave theory of light says that light consists of waves that travel from a source.

When light strikes an object, some light is reflected. We see objects because the light is reflected into our eyes.

Light travels at different speeds through different materials. When light passes from one material into another, it changes speed. The change in speed causes the light to bend. This bending is called **refraction.**

When light passes a sharp edge, it is also bent. This kind of bending is called **diffraction.** Both the particle theory and the wave theory can explain reflection and refraction of light. The wave theory can also explain diffraction, but the particle theory cannot. However, the particle theory can explain how light can travel through empty space, and the wave theory cannot.

Checklist of Science Words

Here are some science words you read about in this unit. Can you tell what you have learned about each one?

crest	particle theory	trough
diffraction	refraction	wave theory

Which Theory?

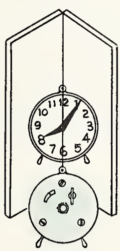
Tell which theory, **A** or **B**, describes each behavior of light listed below. Write the numbers **1** to **6**, and next to each, **A** or **B**.

A. Particle theory **B.** Wave theory

1. Light is made up of tiny particles that move rapidly.
2. Light bends slightly as it passes a sharp edge.
3. Light can travel through empty space.
4. Light forms an upside-down image in the pinhole camera.
5. Light usually travels in straight lines.
6. Light travels out in all directions from its source.

What Is Happening?

Explain what is happening in each of the pictures below.

1


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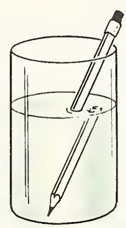

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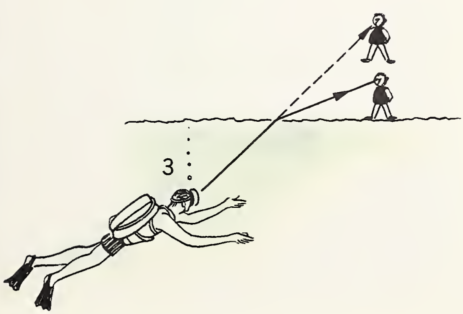

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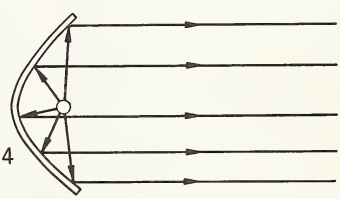


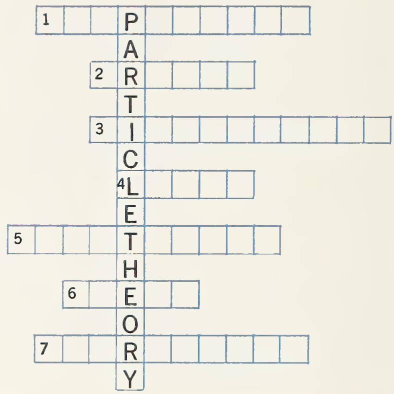
YOU CAN LEARN MORE ABOUT

The Nature of Light

What Are the Words?

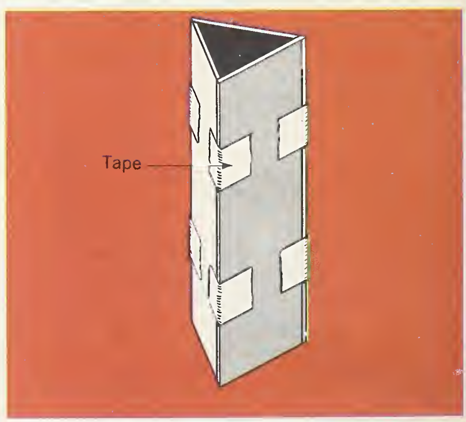
Write the words in your notebook.

1. Newton's word for light particles.
2. The lowest point of a wave.
3. The bending of light as it passes a sharp edge.
4. A form of energy that can be described only in terms of its behavior.
5. The theory that explains diffraction.
6. The highest point of a wave.
7. The bending of light as it passes from one substance into another.



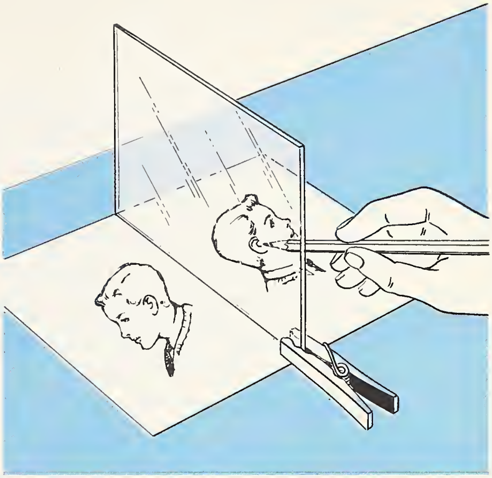
You Can Make a Kaleidoscope

A kaleidoscope is a simple device that can make many images. You will need two mirrors and a piece of cardboard, all exactly the same size and shape. Use rubber bands or tape to hold together the three pieces. Tape a piece of waxed paper over one end. Place a pane of glass on two wooden blocks. Put small pieces of colored paper on the glass. Set the kaleidoscope over the colored pieces of paper. Tap the glass as you look into the kaleidoscope. How does it work?



You Can Copy Drawings by Reflection

You will need a piece of clear glass and a wooden clothespin. Use the clothespin to hold the glass vertically on a table. Place a drawing you wish to copy on one side of the glass and a sheet of white paper on the other side. Look through the glass at the white paper and draw over the reflection you see of the drawing. How does the copy compare with the original drawing? Why does the glass have to be held vertically?



You Can Read

1. *Experiments with Light,* by Nelson F. Beeler and Franklyn M. Branley. Many experiments are suggested to show the nature of light and the working of lenses.
2. *Light and Color,* by Frederick Healey. Discusses the physical properties of light and suggests experiments.
3. *The First Book of Light,* by George R. Harrison. A good general book about light and its properties.
4. *The Wonder of Light,* by Hy Ruchlis. Fascinating photographs and comparisons make this an interesting book.
5. *Understanding Light: The Science of Visible and Invisible Rays,* by Beulah Tannenbaum and Myra Stillman. Many topics as well as the work of various scientists are included.

Do You Remember?

Through the centuries, systems of measurement have been devised and discarded, until the systems we now use were developed. Measurement is vital to almost all scientific exploration.

Units of measurement that everyone agrees upon are called *standard units*. There are two systems of standard units. One is the *English system,* in which the inch, foot, yard, and mile measure length, the ounce and pound measure weight, and degrees *Fahrenheit* measure temperature. The other system is the *metric system,* in which the centimeter, meter, and kilometer measure length, the gram and kilogram measure the mass of objects, and degrees *Centigrade* measure temperature.

Often, scientists want to measure how much material, or *matter,* makes up an object. They use a unit that measures the *mass.* Mass is the amount of matter in an object.

Scientists use *formulas* and *graphs* to show relationships among such things as speed, time, and distance.

Velocity, which is how fast an object travels in a certain direction, is a quantity that can be represented as a *vector.* A vector quantity has both size and direction.

Measurement is important in understanding the relationship between heat and molecules. The molecules of a substance always move at different speeds. Temperature measures average speed of molecules. Heat is the effect of movement of all molecules in a substance. Molecules of one kind of matter move to an area of fewer such molecules. This is called *diffusion.*

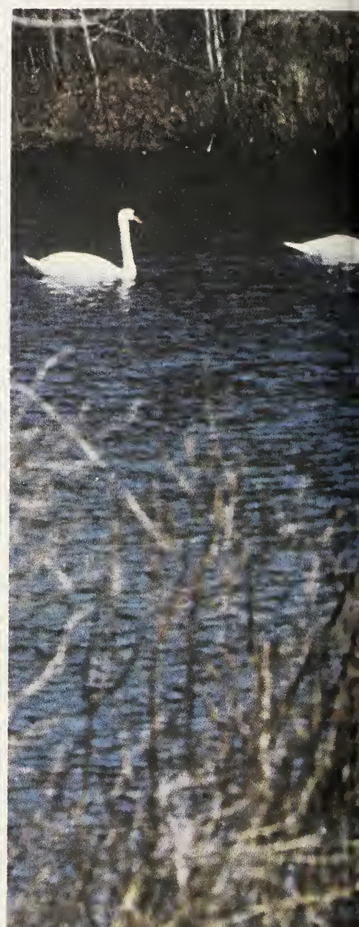
To measure motion of an object, you must measure its speed. You need a device such as a pendulum to measure equal *time intervals,* and a method for measuring distances traveled. An object at rest does not move if forces on it are equal in size and are from opposite directions. These forces are *balanced forces.* To move an object, the balance of forces must be upset. *Frictional forces* may stop an object. Isaac Newton said that if

no other force is exerted on an object, the object will remain at rest or continue to move in a straight line at a constant speed. This statement is known as the *First Law of Motion.* Newton also worked out the mathematical relationship among force, mass, and *acceleration.* This relationship, called the *Second Law of Motion,* says that if you double the force on a certain mass, the acceleration doubles. If you use the same force on a mass twice as great as another mass, the acceleration of the greater mass is only half that of the smaller mass. To get the same acceleration by a mass twice as great as another, you must exert twice as much force as on the smaller mass.

All objects in the universe are composed of matter. Wherever matter exists in any form, electricity also exists. In the *atom,* the nucleus electrically attracts the *electrons.* The electrons also electrically attract the nucleus. But electrons repel other electrons. Thus, there are two kinds of electric forces—attraction and repulsion. Electrons and *protons* are particles of matter that scientists believe cannot be divided further. They are called *elementary particles.* The charges these particles carry cannot be reduced. These are called *elementary charges.* A current of moving electrons generates a *magnetic force.*

Measurement is used in astronomy to find distances to stars. Astronomers use *parallax* to measure distances to objects in space. *Similar triangles* help scientists to measure the sizes of the planets, sun, and moon. We get information about objects in space from light they give off.

Scientists think of light as little packets of energy behaving like waves. Light can travel through empty space. Light usually travels in straight lines. When light strikes an object, some of the light is reflected. The bending of light when it enters a different substance is called *refraction.* The bending of light as it passes a sharp edge is called *diffraction.*



7

Life on the Earth

Materials, Energy, and Living Things

How Plants and Animals Survive

Conserving Our Resources

All the materials found in living things are also found in the earth. Living things are dependent on many of the earth's materials. The energy that a living thing obtains from its food is energy that comes from the sun. Living things cannot create new energy; they can only change energy into other forms.

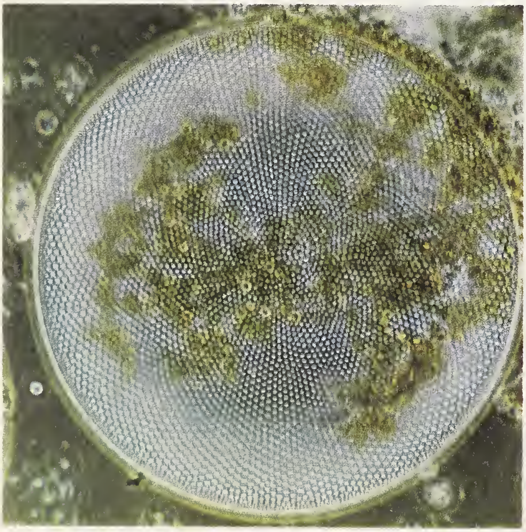
Materials, Energy, and Living Things

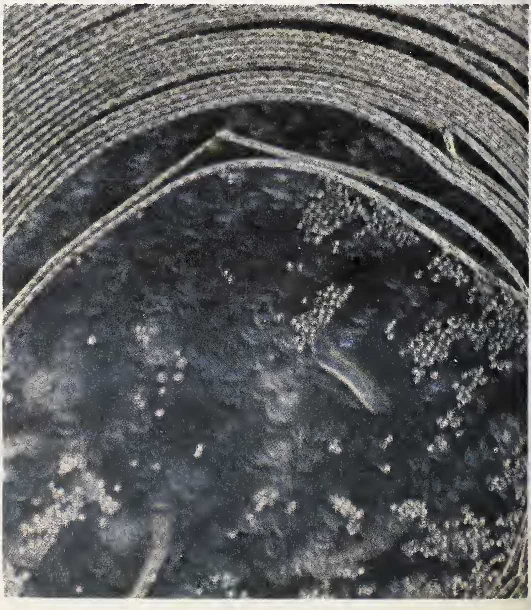
Although living things are made of the same materials as those found in the earth, they differ in many ways from rocks and water and sunshine. You will now learn of the relationship among the elements from the earth, the energy of the sun, and living things.

Green Plants—The Starters

All living things are dependent on other living things—green plants. Green plants link the earth's elements, the sun's energy, and living things. They capture and use the energy of the sun in the process called *photosynthesis*.

How do the one-celled plants shown here serve as links among the earth's elements, the sun's energy, and living things?





In this process, the green plant can be compared to a factory. Raw materials are taken in by the plant to make products that, in turn, are used by living things.

Taking in raw materials and processing them requires a transportation system. A factory's transportation system consists of trucks, railroad cars, airplanes, moving belts, dollies, and elevators. Green plants, especially those that live on land, also require a transportation system. Of what does this system consist?

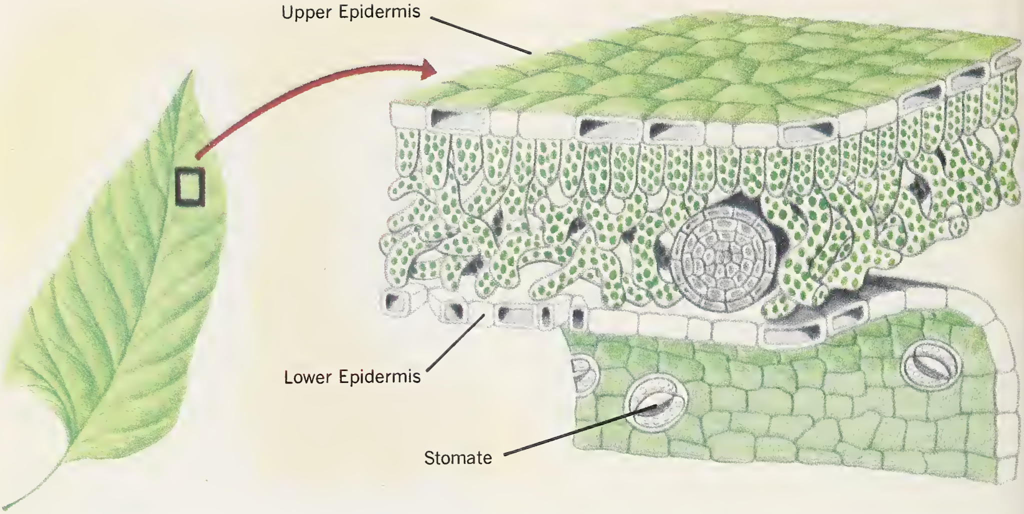
The Transportation System of Plants

When we think of plants, we usually think of those that grow in forests, fields, and gardens. Actually, these are a very small part of all the green plants on the earth. About 90 per cent of the green plants on the earth are found in the oceans. Most of these are single-celled plants such as those shown in the picture on page 236. All green plants need water, carbon dioxide, oxygen, and minerals. Plants that live in water have little difficulty in getting the materials they need. Where do they get their water? Where do they get carbon dioxide, oxygen, and minerals? Land plants, however, have had to develop a transportation system for obtaining water, carbon dioxide, oxygen, and minerals from their environment.

Can you describe the way in which water enters the roots of a plant from the soil?

Water containing dissolved minerals is taken from the soil. Most of the water is absorbed by the very small parts of roots called *root hairs*. You can see these root hairs in the photograph above. Water that is taken up by root hairs moves across the root until it reaches a bundle of very fine tubes. The water then moves up these tubes, through the roots and stem, to the leaves.

If you hold a green leaf up to the light, you can see a network of lines. These are called *veins*. The veins are bundles of water-carrying tubes in the leaf.



What are the small round bodies seen within the cells of the green leaf? How does carbon dioxide enter the leaf? How does oxygen leave the leaf?

Plant some radish seeds. As soon as they begin to sprout, examine their roots with a magnifying glass. Note how very many root hairs there are on one radish root. Remember, it is through the root hairs that water is absorbed by the plant.

Now look at the diagram of the leaf. The covering tissue of the leaf is made of cells tightly packed together. This tissue is called the **epidermis** (ep-uh-DER-miss). Between the cells that make up the epidermis are the cells in which photosynthesis takes place. Can you tell where water passes into the leaf from the veins? Can you tell where carbon dioxide enters the leaf from the air? You will see that there are very small openings in the lower layer of cells. These openings are called **stomata** (STOH-muh-tuh). Carbon dioxide enters the leaf through the stomata.

Capturing the Sun's Energy

How does the green plant use raw materials to make food? First, it splits molecules of water into hydrogen and oxygen. The oxygen is released. The hydrogen is combined with carbon dioxide to form sugar. Work is involved in taking molecules apart and putting them together again. It takes energy to do work.

The Sugar Molecule and Energy

There are several different kinds of sugar. The molecules of each kind of sugar contain the same elements—carbon, hydrogen, and oxygen. The simplest sugar is *glucose*. Its chemical formula is $C_6H_{12}O_6$. The sugar that green plants produce by photosynthesis is glucose. Plants make other sugars from glucose. They also make starch, fats, proteins, and other plant materials from glucose. Plants do not need light to make other materials from glucose, but they do need energy. Since energy cannot be created, where do they get it?

Light energy from the sun is used by the green plants to put together carbon, hydrogen, and oxygen to make a molecule of glucose. Glucose, a form of sugar, is the product of photosynthesis. The energy used is stored in the molecule of glucose. By chemical means the plant can release this stored energy from a glucose molecule and use it to do many things. Remember that the energy from the sugar molecule originally was light energy. By the process of photosynthesis, light energy was changed by the green plant into chemical energy in the form of glucose. All living things depend on green plants to do this.

It was only a little more than one hundred years ago that biologists determined that green plants use water and carbon dioxide to make sugar. Though they knew that green plants need light to do this work, they did not know how they use it. Since that time many scientists have worked on the problem. Today we know much more about how photosynthesis takes place in green plants, but there are still some questions that have not been answered. Scientists in many parts of the world continue the search for more information about photosynthesis.

Chlorophyll

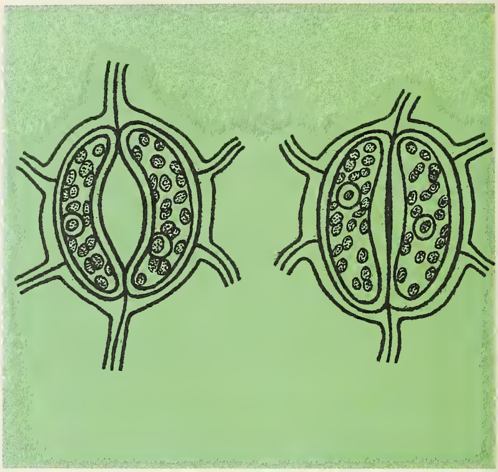
You know that the activities of living things take place in cells. Green plants such as those shown on page 236 are single-celled. Each cell contains the green material *chlorophyll* (KLOR-uh-fil). Chlorophyll makes it possible for a cell to change carbon dioxide and water into sugar by using light as energy.

But what is chlorophyll? This is a question that **biochemists** (by-oh-KEM-ists) have tried to answer for a long time. Biochemists are scientists who study the chemical processes that take place in living things. They have found that there are several different kinds of chlorophyll. Some are more common in one type of green plant than in others.

Chlorophyll is a complicated compound. Its molecules are made up of several elements. The chemical formula for one kind of chlorophyll, called

chlorophyll *a,* is $C_{55}H_{72}O_5N_4Mg$. What different elements make up this molecule? How many atoms of each element are in the molecule of chlorophyll *a*? What is the total number of atoms in the molecule?

The picture at the right shows the cells in a green leaf where photosynthesis takes place. The small green parts of the cells are called **chloroplasts** (KLOR-uh-plasts). Chloroplasts make chlorophyll from materials in the cell. These materials contain atoms of carbon, hydrogen, oxygen, nitrogen, and magnesium.



A close-up of chloroplasts in a green leaf.

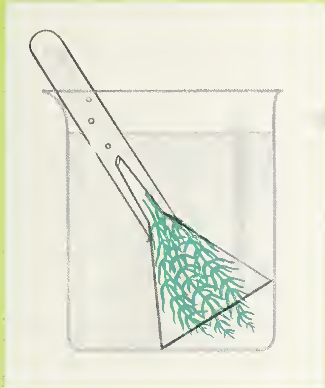
Materials from Green Plants

Animals and other plants depend on green plants for more than energy. The materials that green plants produce also contain the elements that living things need to build cells and tissues. These elements include carbon (C), hydrogen (H), oxygen (O), phosphorus (P), potassium (K), nitrogen (N), sulfur (S), calcium (Ca), iron (Fe), and magnesium (Mg). Green plants obtain some of these elements from the air, some from water, and some from rocks and soil.

Oxygen from Green Plants

You know that all living things use oxygen from the air. They use the oxygen to release energy from food molecules. In this process, oxygen combines with carbon in the food to form carbon dioxide. When oxygen is united with carbon in a molecule of carbon dioxide, it cannot be used by animals. But green plants use carbon dioxide as one of the raw materials in photosynthesis. One of the products of photosynthesis is oxygen. As green plants carry on photosynthesis, oxygen is returned to the air. All of the oxygen in the air is a result of the process of photosynthesis. If it were not for green plants, there would be no oxygen in the air. All living things depend on green plants for oxygen. Can you tell why scientists believe that green plants were among the first living things to appear on the earth?

How Can Oxygen Be Collected from a Green Plant?



What You Will Need

large jar or beaker
glass funnel
test tube
electric hot plate
kettle or pan
5 to 10 sprigs of fresh elodea plant
⅓ teaspoon baking soda
1 quart of water from an aquarium

How You Can Find Out

1. Add ⅓ teaspoon of baking soda to 1 quart of boiled aquarium water and stir until the soda is completely dissolved. This will supply the carbon dioxide that the elodea plants need to carry on photosynthesis.
2. Arrange the elodea plants under the funnel and test tube as shown in the drawing.
3. Place the setup in the sun and observe bubbles of oxygen rise into the test tube. It may take as long as three hours for this process to begin. As bubbles rise in the test tube, water is forced out of it.

Questions to Think About

1. Why is the setup placed in sunlight?
2. What happens when you shade it from the sun?
3. How can you be sure that the gas that you have collected in the test tube is oxygen?

Lichens

Moss

Plants as Soil Makers

Plants also change rocks into soil. The picture at the top of the page shows a rock covered with a crusty plant called **lichens** (LY-kunz). Like other living things, lichens use oxygen and give off carbon dioxide. Some of the carbon dioxide dissolves in water. When this happens, a weak acid called **carbonic acid** (kahr-BON-ik) is produced. Carbonic acid slowly dissolves some of the minerals in the rock. This produces small cracks in the rock. Bits of the rock break off and become mixed with dead pieces of the lichens. Slowly this mixture of rock and plant material increases. After some time, enough of the mixture is produced so that other plants can live on the rock. The mixture is becoming soil.

Moss is one of the plants most capable of living in this newly formed soil. As the moss grows, it produces carbonic acid also. Slowly more and more of the rock is broken up. More dead plant material is mixed with the rock particles. Other plants, such as ferns and grasses, now find the soil a suitable place to live. The rock continues to be broken up as each new kind of plant becomes established in the soil.

After hundreds of years the rock is covered with a thin layer of soil. Very slowly, the soil layer becomes deeper and deeper. After thousands of years, plants such as shrubs and trees can grow in the soil. Their roots grow through the soil to the rock beneath it. Some of the roots enter cracks in the rock. As the roots in cracks grow thicker, the rocks are broken up even more.

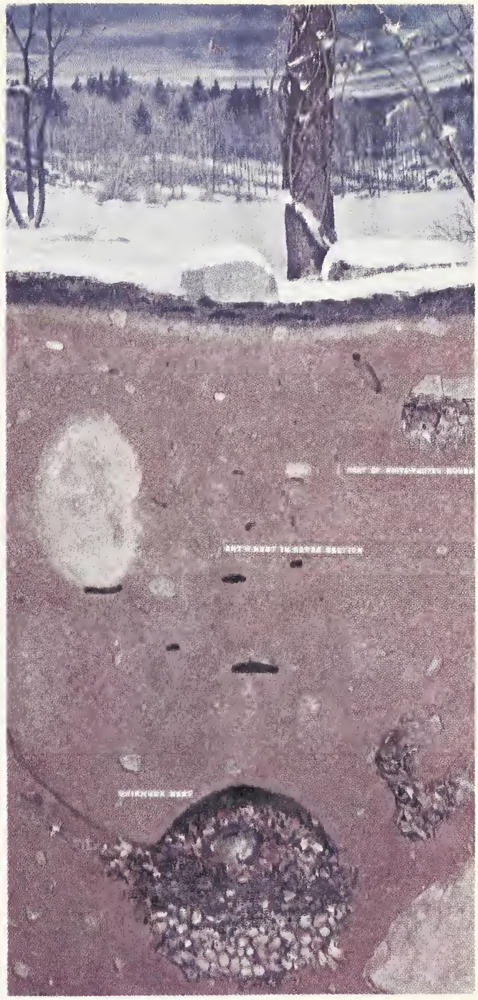
You might want to try to make a lichen garden. Collect rocks with lichens growing on them. Arrange the rocks in a glass jar containing a small amount of water. Cover the top of the jar with a piece of glass or cellophane. If you have a microscope, examine a sample of the lichens torn from the rock. Examine this sample near the torn edge. What does it show you about lichens as soil makers?

Living Things in the Soil

Most soils on the earth have been produced from rock that has been broken up. Soil scientists believe that it takes about a thousand years for one inch of soil to be made.

As you can see in the picture at the right, many different kinds of living things find the soil a suitable place in which to live. Each one adds something to the soil. For example, earthworms and insects that dig into the soil make tunnels through which air and water can enter the soil easily.

To find out what soil contains, spread about a cup of soil over a sheet of paper. Pick out objects that you can identify. Put them in separate piles. Examine some of the soil with a magnifying glass or a microscope. What kinds of materials did you find in the soil? From where did these materials come?



This is a cross section showing life in the soil. What forms of life do you see? How do they survive beneath the soil? How do they get air and food? Notice that this picture shows what the soil looks like in winter. Would life in the soil be different during the summer months? Explain your answer.

The Use and Reuse of Materials

When plants and animals in the soil die, bacteria and molds use them for food. Bacteria and molds obtain energy and materials from dead plants and animals. When dead things decay or decompose, the mineral elements in their bodies return to the soil. They return in a form that plants can use again. Then they can be used again by animals.

Whether living things are in the soil, on the land, or in the ocean, when they die their bodies decompose. The elements in their bodies return to the soil or water and are used again. Living things do not destroy materials. They only use them for a while and then return them to the earth. This is one of the major ideas of science—under ordinary conditions, matter can be changed, but it cannot be destroyed.

Using What You Have Learned

1. How can an aquarium show one of the major ideas of science—that under ordinary conditions matter may be changed but not destroyed? Make an aquarium to find out. What is meant by a balanced aquarium? How does a balanced aquarium show that plants and animals need each other?

2. Obtain some water plants from a pet store or pond. Set each plant in a small jar of water in a sunny place. Watch for bubbles to appear. What are the bubbles? Do they occur at the same rate for each kind of plant? Do they occur in the same parts of the plants? How can you make certain what the bubbles are?

3. Can you explain why you would expect 90 per cent of the green plants on the earth to be found in the oceans?

4. How is a root hair somewhat like a one-celled green plant in the ocean?

5. In what way does the epidermis of a leaf resemble your skin?

How Plants and Animals Survive

Look at the three pictures on page 246. One is a forest, and another is a meadow next to the forest. There are different kinds of grasses growing in the meadow.

There is very little grass growing in the forest. Grass is one kind of plant that needs a large amount of light. Can you tell why there is very little grass growing in the forest?

Look at the other picture on page 246. This is a picture of a meadow high in the Rocky Mountains. Its elevation is about 12,000 feet above sea level. Trees cannot grow at this altitude, because the soil is frozen at depths where the roots of trees would grow. The soil loses heat very rapidly, because the air is thin at this altitude.

Look at the picture on page 247. It shows a grassland prairie. The land is covered with grass, but no trees grow there. The soil is deep and fertile. It is not frozen in the summertime. Trees do not grow there because there is not much water. Trees do not generally grow well in places that have an annual rainfall of less than twenty-five inches. This grassland prairie has only twenty inches of rain each year.

The other picture on page 247 shows a desert. There is very little grass. The soil is good, but there is little water. Generally, there is less than ten inches of rainfall a year in the desert.

As an activity, one student might bring in a rainfall map. Try to pick out parts of the country where you would be most likely to find trees, grasslands, and deserts.

When the early settlers first came to the eastern part of the United States, they found most of the land covered with forests. Trees grew well in that part of the country because the rainfall was more than twenty-five inches a year. Since that time, trees have been removed from much of the land. The land was used for farming. Some of the farms produced good crops, but others did not. Some of the farms that failed to produce good crops did not have the proper kind of soil for crop plants. In other words, the soil was suitable for trees but not for crop plants.

Light, temperature, water, and soil largely determine what kinds of plants will grow in a place. Which condition determines why grass will not grow in a forest? Which one determines why trees will not grow in high mountain places? Which one determines why trees will not grow well on the prairies? Which one determines why crop plants will not grow well in some places where forests have been removed?

Here you see a picture of a meadow high in the mountains. Why is it trees do not grow well in this environment?

Have you ever walked through a forest? Was there much grass on the ground? Where would you find more grass—in a meadow or a forest? Explain your answer.

COMPARING ENVIRONMENTS

On the right is a grassland prairie. This grassland prairie gets very little rain. Why is it trees do not grow well in this environment?

Below is a picture of a desert. Why are very few plants found in this environment? What plants grow well in the desert?

The Regrowth of a Forest

Fires may destroy all the plants that once grew in a pine forest such as that shown below. What would happen to the burned-over land if it were left alone? After a long time, it would again be covered with pine trees. But pine trees would not be the first plants to grow. The first would be plants such as those shown below on the right. The seeds would come from other places. By what methods would the seeds be carried?

For several years, these plants and others like them would grow very well on the burned-over land. Before long, small trees would begin to appear. These would be not pine trees, but

Each year, fires destroy millions of acres of our valuable forest lands.

aspen. Aspen are broadleaf trees and grow more rapidly than pines. The aspen would soon reduce the light so that many of the other plants would die out. After several more years young pine trees would begin to appear among the aspen. Young pine trees grow so well beneath aspen that after a number of years they would grow taller than the aspen. The aspen would not get enough light and would begin to die. After many, many more years the pine trees would take over. A new pine forest would replace the forest that had been destroyed by fire several hundred years earlier. The land would return to a pine forest because the growing conditions are best suited for pine trees.

Read the text and tell why a burned-out pine forest will again become a pine forest.

On the left are sunflowers. On the right are tumbleweeds. Tell how land covered with sunflowers and tumbleweeds becomes a grassland.

The Regrowth of a Grassland

Suppose that a farmer plows up the grass on part of a prairie so that he can grow wheat on the land. After several years, he finds that the land will not grow enough wheat to support him and his family. He leaves his prairie farm. What will happen to the land?

Since growing conditions are best suited for grass, the land will someday become a part of the grassland prairie again. But grass is not the first kind of plant to grow. Tumbleweeds and sunflowers, like those shown in the pictures, grow first. After several years, small patches of grass begin to grow from seeds from surrounding grasslands. Each year, the grass covers more and more of the land. Less water is available for the tumbleweeds and sunflowers. What do you think will happen to them?

Adaptations of a Pine Tree

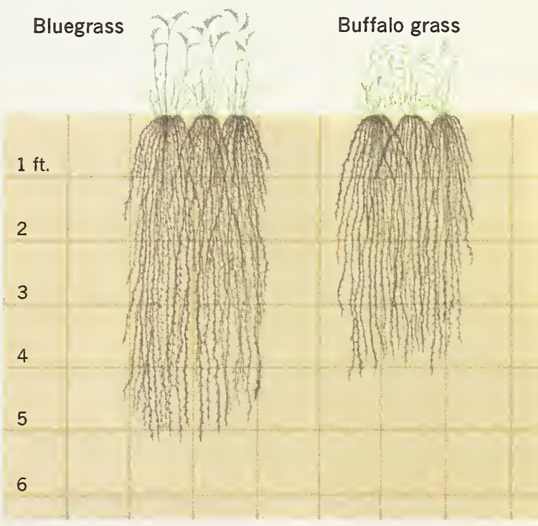
Why will pine trees eventually take over the land where a pine forest once stood? Why will grass eventually take over where there once was a grassland? The answer to both questions is that each is better suited than other plants to grow on that land. The pine trees and the grass are better *adapted* to the environment.

Let us take a look at the ways a pine tree is adapted to its environment. First, young pine trees grow well in reduced light. That is why they are able to grow among the aspen. Second, the pine trees' roots grow deep into the soil. They can get water from deeper in the soil than the aspen can. Third, they grow taller than the aspen. When this happens, light beneath them is reduced. The aspen are not adapted to reduced light. In these three ways, pine trees are better adapted than aspen to the place where a pine forest once stood.

Adaptations of Grasses

In what ways is grass better adapted than the tumbleweed and the sunflower to a prairie environment? Tumbleweeds and sunflowers are rapid-growing plants. Those shown in the picture on page 250 grew from seeds in about three months. Before the plants are killed by cold weather in the winter, they produce many seeds. The seeds can live in the frozen soil during the winter. In the spring, when the soil becomes warm, seeds germinate and another crop of tumbleweeds and sunflowers grows.

How does grass compete with tumbleweeds and sunflowers? Grass seeds are carried in from surrounding grasslands. Like the tumbleweeds and sunflowers, grass produces seeds each year. But the old grass plant is not killed by cold weather. Since the grass does not die each winter, its roots spread through more of the soil



These two kinds of grasses grow on the prairie. How do their root systems enable them to live in very dry regions?

than can the roots of the tumbleweeds and sunflowers. The picture on page 251 shows the root systems of two kinds of grasses that grow on the prairie. Note how dense these root systems are. How would these root systems adapt the grasses to living on the prairies?

Dig up a clump of grass from a vacant lot or field. Wash the soil from the roots by moving the clump up and down in a bucket of water. Is it possible for you to count the number of roots on one clump of grass?

Carefully dig up a dandelion plant that has been growing in a lawn. Can you tell why grass does not grow near the dandelion?

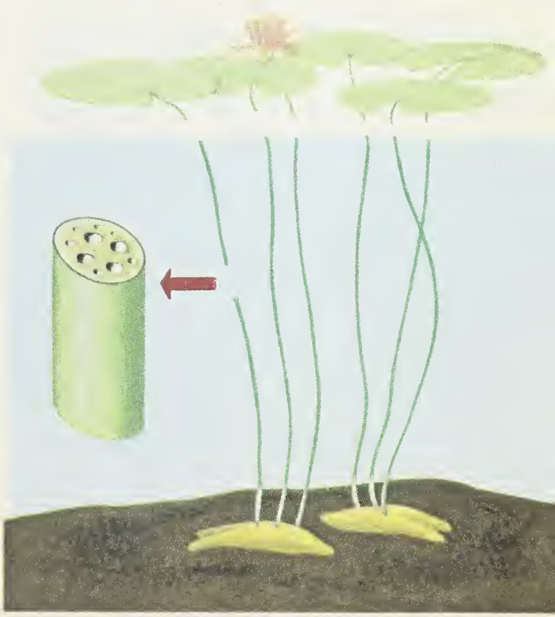
Adaptations of Cactus

A cactus plant is adapted in three ways to living where there is very little rainfall. First, the roots of a cactus plant spread over a wide area and do not grow deep into the soil. This makes it possible for the plant to absorb more water near the surface of the earth. How would this help the plant? Second, the stem of the cactus plant is very thick. It has many large cells in it. These cells can hold much more water than ordinary stem cells. How does this help the plant? Third, the leaves of a cactus plant are extremely small. In fact, they are the thorny spines on the stem. How does this help the plant?

Name three ways a cactus plant's structure enables it to survive in dry regions.

Adaptations of Water Lilies

The picture above shows plants growing in water. They are called water lilies. Some plants, such as bean plants, do not grow well in water. They die because their roots cannot get air from the water. How do the roots of water lilies get air? Air passes down from the leaves through the stem. The picture at the right shows the hollow tubes in the stem through which air passes. How does air get into the lily leaf?



Adaptations of Animals

You know that there are many different kinds of animals in different parts of the earth. Large herds of buffaloes once lived on the prairies in the United States. Here they found the grass they needed for food. Buffaloes could not have survived in a forest.

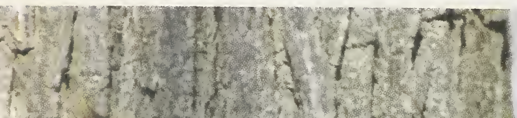
Deer are found in and near forests. Deer live on the tender shoots and leaves of trees and shrubs. Could deer survive on a prairie?

Camels, which are used for doing work in the Middle East and North Africa, can go many days without water. They can also run easily over both sand and hard rock on their flat, padded feet.

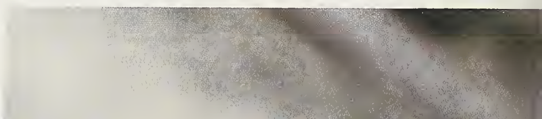
Reindeer, which live in the arctic regions, dig through ice and snow with their sharp-edged hoofs to find lichens. Like camels, they are strong runners—but could they survive in the desert?

Tree squirrels live where there are trees. They eat the seeds from trees and use trees as nesting and hiding places. The ground squirrel lives on the prairies. It lives in burrows and eats the plants that grow on the prairies. Could a tree squirrel live on the prairie? Could a ground squirrel live in a forest? Explain your answers.

Tree squirrel



Ground squirrel



Animal Protection from Predators

One of the most important problems animals have is that of protecting themselves from other animals. Animals that attack other animals for food are called **predators** (PRED-uh-terz). The mountain lion is a predator of deer. The coyote is a predator of rabbits. Some hawks are predators of smaller birds. In lakes and oceans, large fish are usually predators of small fish and fish eggs. In arctic waters, polar bears hunt and eat seals, which in turn live on the fish that they can catch through the ice.

Some animals have adaptations that help to protect them from other animals. For example, the porcupine's body and tail are covered with sharp, pointed quills. These quills usually lie flat on its body, but when the porcupine is disturbed, the quills stick out, as in the picture above at the right. When the porcupine is attacked by another animal, its quills stick into the animal. When the animal moves away, the quills go with it! Each quill has sharp barbs, like a fish hook, and it is very difficult to remove.

Male deer have antlers, which they use to protect themselves from coyotes and mountain lions. They may also use their hoofs. However, the best protection that the deer have is their ability to run very fast.

You have learned about two ways animals protect themselves. Can you name other ways? How do dogs and cats protect themselves? How do birds and caterpillars protect themselves?

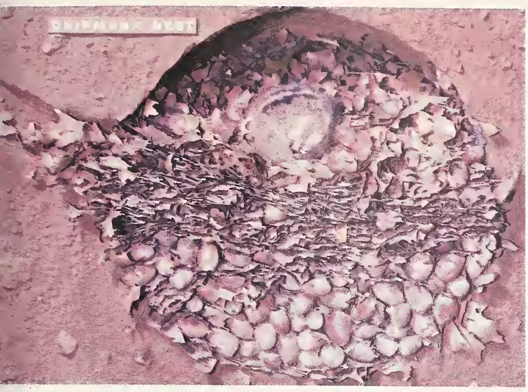
A young deer, or fawn, is protected in another way. As you can see in the picture above, the coloring of the fawn's coat makes it difficult to see. This is called **protective coloration.** Do you know of other animals that are protected by coloration?

Hibernation and Migration

Animals are adapted to seasonal changes in temperature. Some animals, such as woodchucks and ground squirrels, sleep during the winter. This is called **hibernation** (hy-ber-NAY-shun). Animals that hibernate eat a great deal of food during the summer, and they are quite fat by the time winter comes. During their long winter slumber, they do not eat. The fat in their bodies keeps them alive. Do you know of some other animals that hibernate?

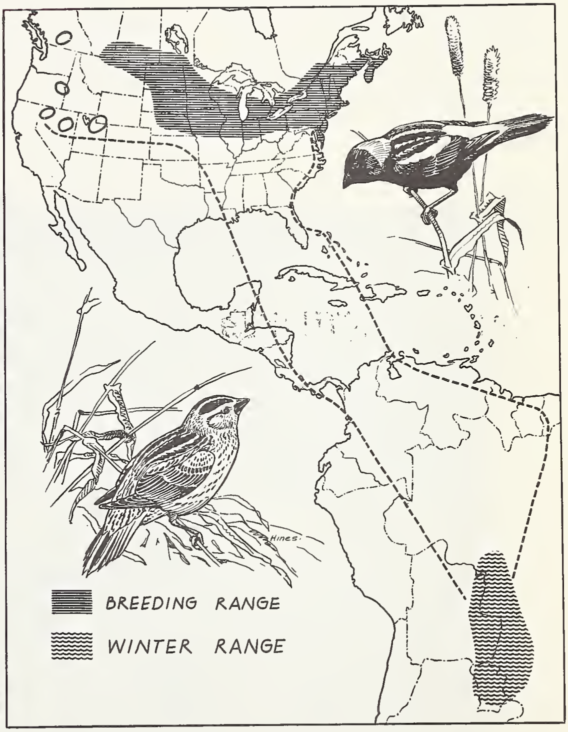
Some animals move from places where it is cold in the winter to places where it is warmer. This is called **migration** (my-GRAY-shun). Many different birds migrate from the north to the south during the Northern Hemisphere's winter. Some birds migrate great distances. For example, the arctic tern travels 10,000 miles from its summer home in the northern part of North America to its winter home near the southern tip of South America. The bobolink is another great traveler. It spends the summer as far north as the Hudson Bay in Canada. It spends the winter in Argentina, South America. Name some birds that spend only a part of the year where you live. Where do they go for the rest of the year?

Why do only some kinds of birds migrate? How do they know when to begin their migration? How do they find their way? Scientists are still trying to find the answers to these questions.



The Chipmunk spends much time under ground in a nest during the cold days of the winter.

The ground squirrel spends the winter hibernating underground. Look at the two maps below and tell how the arctic tern on the left and the bobolink on the right spend their summers and winters.



How Environment May Change

Different kinds of living things are found in and around a pond. Several kinds of fish and water insects can be found in the pond. Ducks and other water birds can be seen on the water. Water lilies grow in the water near the edge of the pond. Cattails and other kinds of high grasses that are adapted to wet soil surround the pond. Here and there are some birch trees and shrubs that can live in moist soil. The surrounding hills are covered with trees.

Each kind of plant and animal is adapted to the special conditions under which it is living. But the environment is constantly being changed by the plants and animals living in and near it. As the water plants and animals die, their bodies slowly fill the pond. As rain water runs from the surrounding land into the pond, it carries dead leaves and other material. Slowly the pond becomes smaller and smaller. After many years, there will no longer be a pond. What plants and animals will no longer be living there? What new ones will move in?

How many years back can you remember? Has the place where you live changed much in that time? Are the summers warmer? Are the winters colder?

How may this environment change in time?

The United States—20,000 Years Ago

If you had been living in the United States 20,000 years ago, you would have found it very different. At that time a sheet of ice extended from the North Pole over most of the northern part of North America, which was colder than it is now. The time was known as an "ice age." During the past million years there have been four ice ages. Ice sheets reached as far as the places now occupied by St. Louis, Missouri, in the Midwest, and New York City, in the East. The sheets of ice were as much as a mile thick. As they slowly moved southward, they pushed soil and rocks ahead of them. Most of New England's good soil was scraped away by advancing mountains of ice. The soil and rocks were pushed into the ocean off the coast of Connecticut. The strip of land known as Long Island was formed from New England's soil and rocks.

You can see that the environment changed greatly during the ice ages. Animals that lived in the northern parts of the country moved south ahead of the cold ice. Plants were destroyed. As it became warmer, the ice slowly melted. Animals moved northward again. Plants began to grow again on land that had once been covered with ice.

These changes took place gradually. It has taken about 20,000 years for the ice to melt back as far as the ice cap that now surrounds the North Pole. In the years since Columbus discovered America, for example, it has not been possible to observe any great change in temperature. Recently scientists have been trying to find out whether the ice cap around the North Pole is getting larger or smaller. If it is getting smaller, the ice is still melting. Some day the Arctic Ocean around the North Pole may have much less ice in it. If the ice cap is getting larger, another ice age may have begun. If this is true, then 20,000 or more years from now the land may again be covered with ice.

A Rapidly Changing Environment

Of course, there are ways in which the environment can change very rapidly. For example, in 1883 a volcano erupted on the small island of Krakatoa, near Java, in the East Indies. The eruption was so violent that every living thing on the island was destroyed. Since then scientists have carefully studied Krakatoa to learn more about how living things become established again.

Three years after the eruption, there were 26 different kinds of plants growing on Krakatoa. Ten years later, the

A volcano burns near Krakatoa. Steam and gases rise high as hot lava pours forth.

island was plentifully covered with green plants. Twenty-five years after the eruption, 263 different kinds of animals were living there. Less than fifty years after all life had been destroyed on Krakatoa, the island was again covered by a young forest. Many more kinds of animals had also become established since the eruption. How did all this happen? From where did the plants come? How did they get to Krakatoa? From where did the insects and birds come? How did they get to Krakatoa?

Have you ever seen land from which all plants were removed? This often happens when houses or highways are being built. How long did it take before plants were growing again on the land? As you can see, it would be extremely difficult to destroy all living things on the earth.

Dandelions and Codfish

If you help to take care of a lawn, you know how difficult it is to keep the weeds out of it. The dandelion is one kind of weed that seems to grow well in lawns. You can dig dandelions out of your lawn, but soon new ones take their place.

Why are dandelions so difficult to control? One dandelion plant produces a number of flowers. Each flower produces many seeds. Each seed is attached to a small "parachute" that is easily carried by the wind. Dandelions begin producing seeds early in the summer. During the rest of the summer, dandelion seeds are being distributed. Because of the large number produced, it is likely that some of them will be carried to your lawn. Many of them will lie on top of the grass and never germinate. However, some will be washed into the soil by rain. Some of these will germinate. Not all the seeds that germinate will develop into fully grown dandelion plants, but the ones that do will cause you trouble.

What would happen if all the seeds developed into dandelion plants? In a few years, your yard would be covered with dandelions. In fact, it would not be long before acres of land would be covered with dandelions. Can you tell why this does not happen?

Suppose each dandelion produced only one seed. What would happen to dandelions? One reason that dandelions are able to survive is that they produce a large number of seeds. How many seeds does a dandelion plant produce? You and your classmates can answer this question if each of you can find some dandelion plants. Carefully collect all seed heads from a dandelion plant. Count the number of seeds on each head. Find the average number of seeds per head. Estimate the number of seed heads produced by one plant during a growing season. Multiply your estimate by the average number of seeds. This will give you an approximate number of seeds per dandelion plant. It will be a large one. Compare your answer with those of your classmates.

You know that large fish eat smaller fish and fish eggs. How, then, is it possible for some small fish, such as codfish, to survive? A female codfish lays as many as six million eggs at one time. Many of the eggs never hatch, because they are eaten by other fish. After the remaining eggs have hatched, many of the small fish are eaten by larger ones. Even though only one grown codfish may survive from one million codfish eggs, codfish remain in the ocean.

Interdependence of Living Things

In this unit you have learned about the ways in which living things are dependent on materials from the earth and energy from the sun. You have learned that green plants make the materials and energy available to other living things. Finally, you have seen how living things compete with one another for food, light, and water.

During the millions of years that life has existed on earth many kinds of living things have developed. So far, scientists have discovered more than a million different kinds of plants and animals. Each kind is dependent on other kinds in some way. Even green plants are dependent on bacteria and molds to decompose dead plants and animals. All living things are interdependent. The pictures on this page show some ways in which living things are interdependent. Can you explain the pictures?

Balance in Nature

The mule deer is adapted to living in a mountain environment where shrubs and small trees grow. Much of its food comes from the buds and tender leaves of these plants. Mountain lions are adapted to the same environment. Their food comes from the deer they kill. Generally, the deer population does not increase for two reasons. First, the shrubs or trees produce only enough food to feed a certain population of deer. If the deer population increases, there will not be enough food. Some of the deer will die. Second, the mountain lion kills enough deer to keep the deer population about the same from year to year. The population of mountain lions remains about the same because the population of deer does not increase. There is a balance between the mountain lion population and the deer population.

There are many other examples of balances between and among living things. In what way is each of the following pairs of animals in balance?

1. Owls and mice
2. Rabbits and coyotes
3. Small birds and hawks
4. Mantises and grasshoppers
5. Ladybird beetles and cottony-cushion scales

Changing the Balance

What would happen to the deer population if all the mountain lions were killed? Hunters actually have killed them all in some places, and the results are well known. The deer population increases rapidly until there are more deer than the food supply can support. Many of the deer die of starvation, reducing the size of the population until a new balance is reached between the deer population and its food supply.

At one time it was considered necessary to kill hawks to protect birds and chickens. However, when the hawks were killed, the unwelcome mice and gopher populations increased. A good rule to follow is to find out the effects of reducing or increasing the numbers of one kind of animal before attempting to do so.

The idea that as civilization spreads, all wildlife becomes scarcer is false. Many animals have been very successful in adapting to the changed conditions brought about by man. For example, the coyote, the Colorado potato beetle, and the opossum have increased in numbers and spread to new areas. House mice, houseflies, bedbugs, sparrows, and starlings seem to live and thrive better in man-made environments than they do in the wild. Can you think of other examples?

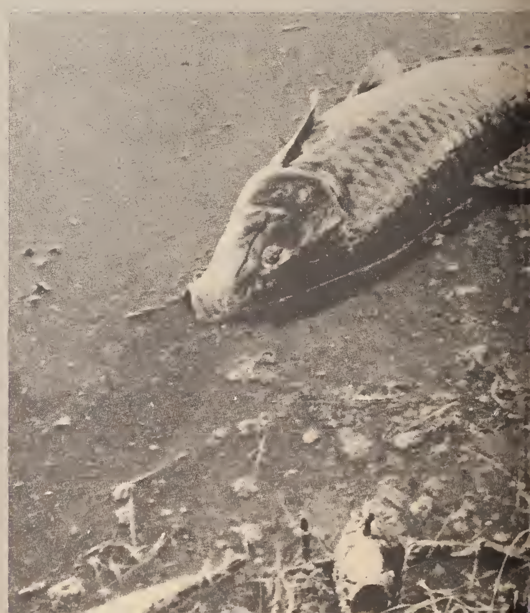
Rachel Carson

(1907–1964) United States

Rachel Carson was born and grew up in the small town of Springdale, Pennsylvania. There, and in the surrounding countryside, her mother taught her to love the world of living plants and animals. She learned from her mother that every living thing has its place in nature and performs some useful function. It is only mankind that thinks of some flowers as "weeds," or insects as "pests." In nature there are no "weeds," no insect "pests."

When Rachel Carson grew up she became a biologist. In her studies she learned that in all of nature there is a *balance* among all living things. This balance prevents plants and animals from doing harm to men, to the countryside, or to themselves. When the balance of nature has been upset for some reason, plagues and epidemics occur.

After college, Rachel Carson went to work in Washington, D.C., for the Fish and Wildlife Service. In her spare time she wrote books about the beauty and wonders of nature. These books—*Under the Sea Wind, The Sea Around Us,* and *The Edge of the Sea*—made her famous.



During World War II, many different insect poisons—pesticides—were invented to help protect our soldiers overseas against disease. DDT was the most famous. After the war, these pesticides were used by farmers to kill the insects that destroyed their crops. Many farmers used these pesticides without thinking of the upsetting effects that they might be expected to have on the balance of nature.

In the countryside, the chemicals soaked into the ground and were washed into streams by rain. The fish in the streams and rivers began to die. Birds who fed on poisoned insects also began to die. Meanwhile, an even more alarming process was beginning to take place. The insects themselves became immune to the pesticides and began to increase in numbers even as their natural predators were dying off. Slowly, silently, the balance of nature was being upset. Scientists began to worry about whether these poisons could upset the balance of nature permanently and harm mankind.

To warn the American people of what was happening to their country through the indiscriminate use of pesticides, Rachel Carson wrote her most famous book, *The Silent Spring*. The title refers to the silence that now greets the early riser in the springtime instead of the symphony of birdsongs he used to hear in the morning. Rachel Carson hoped her book would make Americans aware of the problems that arise from using pesticides. Whether it will or not remains to be seen.

Using What You Have Learned

1. Why are there very few trees growing on the grassland prairies?

2. Why have farms been unsuccessful in some places where trees once grew?

3. Why are trees planted on burned-over lands even though trees would eventually grow there again if the land were left alone?

4. Why do weeds seem to grow better in your garden than the plants you want to grow there?

5. Give examples of some ways in which animals are protected from their natural enemies.

6. List ways in which the environment in your community has been changed by the activities of people. How have these changes affected living things?

7. How may each of the following change the environment?

a. Reduction of the average annual temperature for a long period of time
b. Increased volcanic activity
c. An upthrust of mountains
d. Much heavier than average rainfall over a period of several months

8. Tell how each of the following pairs of living things is interdependent.

a. Apple trees and bees
b. Forest trees and birds
c. Aquarium plants and fish
d. Green plants and bacteria
e. Aquarium snails and fish

Conserving Our Resources

We depend, as do other animals, on air, soil with its minerals, water, and all other living things. These are our *natural resources.* We have been using up these resources faster than they can be replaced. Chemical factories, paper mills, steel mills, food-processing plants, electric power plants, oil refineries, and hundreds of other kinds of industries use our natural resources to make medicines, newspapers, books, construction materials, foods, heating materials, and many other products and materials that are a part of our everyday lives. Industry has grown rapidly in this century. As new discoveries and inventions are made, industry advances to supply us with the products and materials of the scientific age. As industry tries to meet our needs, problems are created—minerals are used up, water and air become filled with the smoke and dirt of large factories, and animals and plants die as their environments are destroyed.

Whether we live on the farm or in the city, it is our responsibility to look toward the future and to plan so that tomorrow's world will have plentiful resources as we do today. Managing these resources is called **conservation.** *Conservation* means using our resources wisely.

Since conservation problems are mostly man-made problems, they can be solved by man.

Soil Conservation

Many forests have been cut down. As rain falls, it washes away the soil where there are no trees to hold back the water. The soil is washed away into gullies and rivers and finally into the sea.

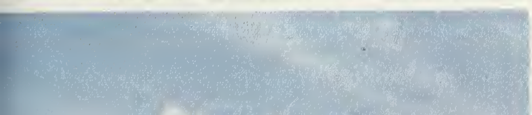
Grasslands have been plowed up to plant wheat and other crops. They have been overused for the grazing of sheep and cattle. When land is misused in this way, rain and winds may carry much of the precious soil away.

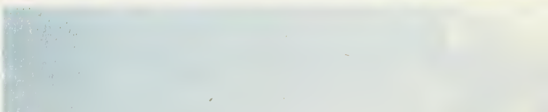
Since the time when the early pioneers came to America, we have lost one third of our good soil. At the same time our population has greatly increased. We must raise crops and food animals to feed the population. We are faced with the problem of learning how to raise more and better crops and pasture animals without ruining what is left of our good soil. We must also learn how to build up more good soil.

On the next two pages you can see some of the ways man now manages the land to build up fertile soil and to prevent it from wearing away.

EROSION AND CONTROL

On the right you see a gulley formed by the forces of erosion. The pictures below show how the gulley was filled in and a ground cover grew over the land. How does the ground cover prevent erosion? Look at page 269. What methods are being used to prevent erosion?





Water Conservation

Make a list of all the ways you use water in one day. A hundred years ago, people did not use much water for bathing and washing. There were no water fountains or water coolers. Industries used very little water compared to the amount used today. We use vast amounts of water in many, many ways. We are using it at such a rapid rate that it cannot always be resupplied by rain and snow fast enough to meet our needs. And so we have water shortages.

Rivers have always been a principal source of usable water. Today the waters of only a few rivers are usable. Most of our rivers have been ruined by sewage and industrial waste.

The Potomac River in Washington, D.C., was once a favorite swimming place for people who lived near it. Today, the river gives off foul odors on hot, humid days. Towns all along the Potomac have sewage-disposal plants, but none is large enough to handle the present volume of sewage. Therefore raw sewage enters the river. This condition is repeated across the land in many other rivers.

Towns, cities, and states are now passing laws to keep our waters clean. Industrial plants are finding other ways to get rid of their wastes. Better sewage-disposal plants are being developed. But there is still much to do to make our waters clean and safe.

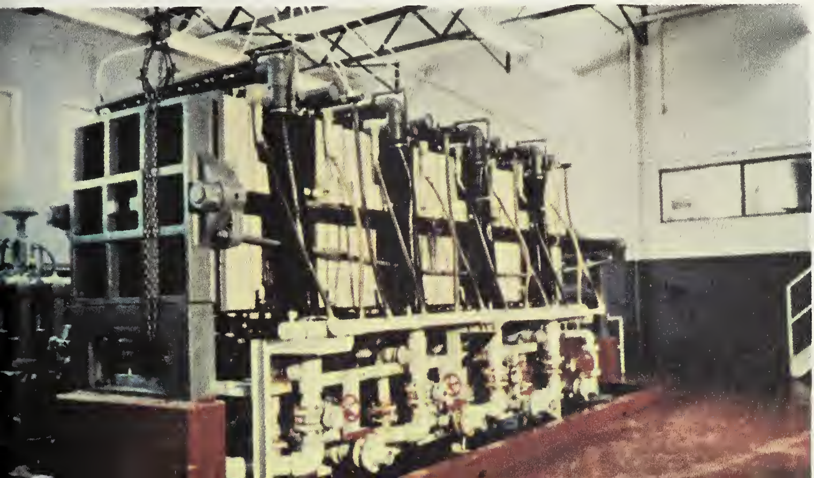
How may many floods be prevented?

Has there ever been a flood in your town? What caused the flood? Many floods occur after sudden and large rains or long-continued rains. The flood waters come from water that runs off the soil quickly. Water runs down bare hillsides or mountains at great speeds, swelling streams and rivers until they overflow and causing floods.

Flood water is water that did not have a chance to soak into the soil. The problem is how to give more rain water a chance to soak into the land. On the following page you will see some of the ways that have been developed to conserve water.

On January 1, 1965, The International Hydrological Decade began. For ten years, many scientists in many parts of the world will try to understand the water cycle better. This project is aimed at finding ways to prevent the loss of great amounts of water by evaporation and other natural and man-made means. Scientists also hope to encourage colleges and universities to train more scientists in hydrology—the study of water.

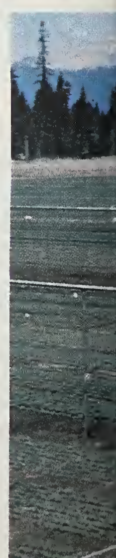
On the left, scientists test water samples for pollution. Above, you see a dam. How do dams conserve water? Below is a plant for changing sea water to safe drinking water.



Forest Conservation

From our forests come logs for lumber and wood for building materials, pencils, and matches. Rayon, cellulose, alcohol, glue, medicine, and other products come from our forests. Forests also provide recreational areas for people and homes for wildlife. And forests help prevent floods by reducing water runoff.

Each year our forests become more valuable to us. Each year more trees are needed to meet the needs of our growing population. Ways have been found to harvest lumber without doing away with our forests. To do this our forests must be properly managed. Proper management means that the older trees in a forest are cut first. New trees are planted to replace those cut, and these trees are protected from insects, fires, and disease.



FOREST CONSERVATION
Study the pictures carefully and then make up a story to explain each picture. Tell how each picture shows a forest conservation practice. Are you doing your share to conserve our forests?

But proper management of our forests will not protect them from man's carelessness. Each day there are about 500 forest fires in the United States; each year, about 180,000 forest fires. More than 90 per cent of these fires are caused by people. Sometimes a match is carelessly tossed away. Often campfires are not completely put out. It is up to the people who use the woods to prevent forest fires. Do your share: Be careful with fire whenever you visit a forest.

In some parts of our country, smokestacks such as these pour forth pollutants into the air we breathe 24 hours a day. What role must the public play in seeing to it that our air is clean?

Conserving Our Air

There is poison in the sky. This poison is **polluted air.** At times we can see it—a grayish smoke that hangs over the land, hiding the sun. We can also smell and feel it. Polluted air stings our noses, burns our eyes, and scratches at our throats and lungs.

After a while it seems to disappear, and our skies are once more clear. But it leaves its marks. Plants may be wilted, cattle and other livestock may be ill, plant leaves become coated with a glaze, crops such as lettuce, beans, and alfalfa are damaged, metal is corroded, stone and paint are eaten away, and people suffer with a lingering cough.

If the polluted air settles low over the ground, visibility is reduced and traffic hazards are produced for automobiles and airplanes. Doctors say that polluted air can aggravate heart and respiratory conditions.

Man is responsible for polluted air. Anything that pollutes the air is called a **pollutant.** The great number of industries created by man pour great amounts of pollutants into the sky each day. Fumes from steel mills, power plants, and petroleum and chemical plants often cover dozens of square miles with clouds of black smoke. Exhaust fumes from cars and trucks and buses add to the pollution in the sky. Even the burning of leaves in the backyard sends pollutants into the air.

Whether the pollutants in the air will be dangerous depends on the weather. Usually winds blow the pollutants in the air over mountains, across seas, and over unpopulated stretches of the earth. Snow and rain wash the air clean, washing the pollutants down to the earth. But sometimes there is no movement of air. This happens when a blanket of warm air lies over cooler air near the surface of the earth. This condition may last a few hours, a few days, or even longer before a wind blows the warm air away. There are times when smoke and fog form a mixture called **smog.**

In December, 1962, the city of London, England, was covered by a blanket of gray-brown smog that slowed traffic, made seeing difficult, and darkened the sky. In the four days before winds finally moved the smog, more than 700 people had lost their lives because of it. New York had a similar experience in 1953, and 240 people died as a result of the smog.

The London smog of December 1962 made it difficult to see all but close objects. People covered their faces with scarves or special masks to keep out the dirt and chemicals the air contained. Below, smog covers a major city in the United States.

In 1946, smog covers a tunnel opening in Philadelphia. You see the same tunnel in 1956, after smoke-control measures were taken to reduce air pollution.

The Division of Air Pollution of the United States Public Health Service and city and state departments of air pollution are trying to combat this problem. Congress has made federal funds available to state and local air pollution control agencies for research.

Many industries have changed to fuels which have very little pollutant-creating material in them. Filters have been installed to prevent dangerous material from escaping. Laws have been passed to stop the burning of trash and leaves in backyard incinerators.

The United States Weather Bureau and the Public Health Service have set up the National Air Stagnation Alert System. This nationwide network operates on an around-the-clock basis, recording weather conditions that might favor the accumulation of air pollutants. The records of weather conditions are analyzed, and warnings are sent to areas that might be in danger of hazardous pollution.

Conserving the purity of the air is one of the most important problems in our country today.

Conserving Our Wildlife

You will never see the animals pictured on this page alive. Today you can see them only in photographs and in museums. Not too long ago, however, large numbers of these animals lived. People thought that no matter how many were killed, there would always be more. No record was kept of the number of animals killed. Because of man's carelessness, these animals are **extinct**—they no longer exist.

Many kinds of animals are on the verge of extinction. Many of these animals, such as the whooping crane, of which there are less than fifty in the world, are being protected from extinction by the government.

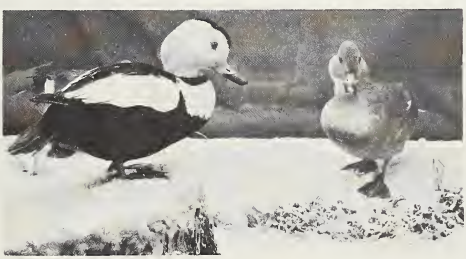
EXTINCT ANIMALS

Great auk

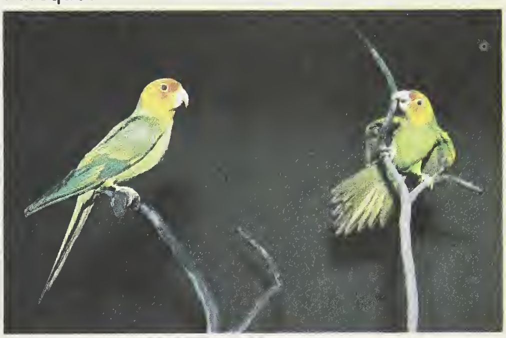
Passenger pigeon

Eskimo curlew

Labrador ducks



Paroquet



Heath hen

In 1964 a national effort to save the giant California condor was started by the National Audubon Society. The Society, which helped to save eagles from extinction shortly after 1900 and is currently trying to preserve the few remaining whooping cranes, has set up a five-point program to save the condor.

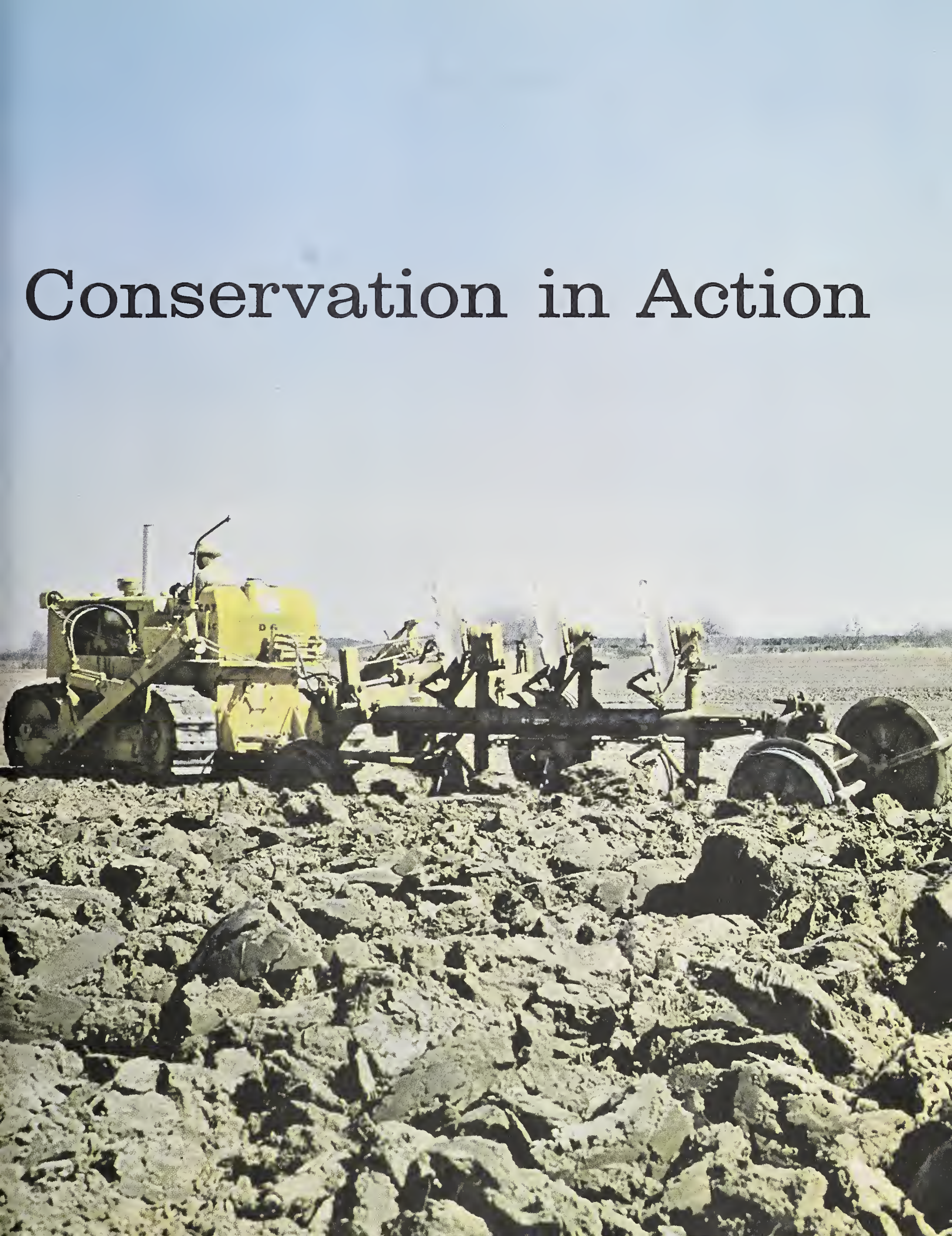
The condor is a bird with a wingspread of over eleven feet. Early pioneers of America, such as those with the Lewis and Clark expedition, called it the "royal vulture." Indians called it the "thunderbird," because they thought that the flapping of its wings made thunder. A hundred years ago there were countless condors. Fifteen years ago there were only sixty. Today there are only forty. The disappearance of the condors is the fault of irresponsible hunters who are killing them faster than they can reproduce.

1. It will try to have present laws against killing condors better enforced.
2. It will employ special condor wardens to patrol the lands on which the condors live.
3. It will start an education program for the public.
4. It will set up protective zones around the lands on which the condors live.
5. It will urge various agencies to avoid the use of chemical pesticides that might kill the birds.

ABOUT "CONSERVATION IN ACTION"

The United States government is concerned with the management, conservation, and development of the nation's water, fish, forest, wildlife, mineral, and park and recreational resources. It works to assure that nonrenewable resources are developed and used wisely — now and in the future. In this picture story you will see and read about the United States' conservation program in action.

Conservation in Action



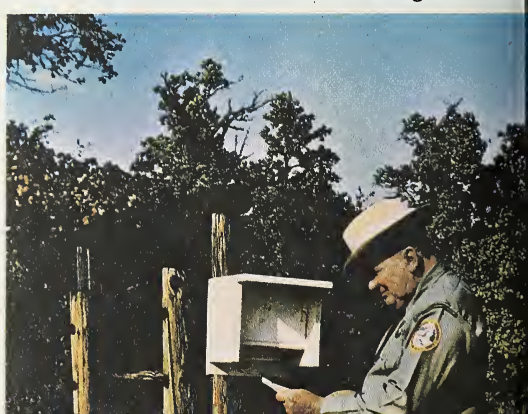
WILDLIFE REFUGES

The United States government has set aside millions of acres of land to be used as wildlife refuges.

Hundreds of birds flock to the Bear River Migratory Bird Refuge, in Utah. Here they are protected so that they will increase in number and spread to surrounding areas.

Another refuge is Wichita Mountains National Wildlife Refuge, in Oklahoma, where bison protected from hunters roam on vast areas of land.

A refuge manager's job is to make sure that the wildlife is protected. He sees to it that there is enough food and shelter for the animals to raise their young and that hunters do not unlawfully hunt animals on the refuge. Here you see a refuge manager stocking a container with leaflets to inform visitors about the refuge.



This is another bison refuge, in Montana, operated by the Department of the Interior's Fish and Wildlife Service.

Water control is one of the Fish and Wildlife Department's responsibilities. Here two employees are checking a water control structure.

Thousands of people each year visit the refuges. In this picture, you see a manager holding a rattlesnake at bay during an Audubon Society visit.

Fishing is permitted on many refuges.

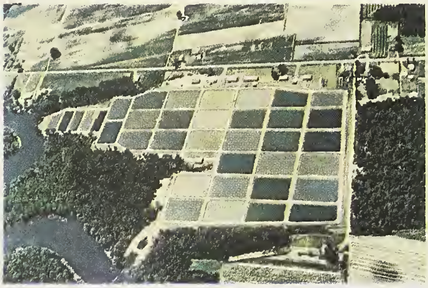
Banding birds such as ducks is also a job of those who work on refuges.

Fish derby catches are weighed at Tishomingo National Wildlife Refuge in Oklahoma.

FISH HATCHERIES

More than one hundred National Fish Hatcheries operated by the Fish and Wildlife Service are located throughout the country to help manage our important sport and commercial fishing resources.

Hatcheries raise the kinds of fish that are most needed for fishery resources in the area. This is Spring Creek National Fish Hatchery in Washington.



This is the Edenton National Fish Hatchery in North Carolina. It is a pondfish hatchery. It produces largemouth bass, bluegill and channel catfish, and other warm-water fish. The ponds are each fertilized, and in this picture you can see different stages of plankton growth. Which areas have the most plankton? How can you tell?

Here the eggs are being gently stripped from a female rainbow trout while milt is added from the male. What does the milt do?

Here you see newly hatched trout living on nutrients drawn from their attached yolk sacs.

Fish are weighed before being released to a farm fishpond.

Trout are stocked in public fishing waters in a National Forest.

Insulated tank trucks carry large loads of live fish great distances with safety.

Fishery biologists check fish at the hatcheries for disease.

FOREST CONSERVATION

The United States has about 182 million acres of valuable forests. These public forest lands are scattered from Puerto Rico to Alaska. These are our National Forests. National Forests provide not only timber but also protection for the watersheds of streams. They also provide food for livestock, homes and food for wildlife, and recreational facilities for people. All these resources are managed by Forest Rangers to provide the greatest possible use.

Forest Rangers are trained through college study and practical experience to manage timber, range, water, recreation, and wildlife resources.

Insects and disease kill more trees every year than do fires. Rangers watch for diseases caused by insects and try to prevent them from spreading. One of the most destructive diseases is white pine blister rust. It is controlled by spraying the pines with an antibiotic fungus killer.

This woman serves as lookout during periods of fire danger. If she sees a fire she alerts the Forest Ranger station.

The Forest Rangers are prepared for emergencies such as fires. Modern machinery is immediately put into action.

Airplanes drop a special powder to put out fires.

Helicopters drop loads of water.

Many forest fires are caused by carelessness. If you use our National Forests, be careful — prevent fires!

SOIL CONSERVATION

Soil conservation is another important job of the United States government's conservation program. Here you see some of the work done by the Soil Conservation Service. For more information write to the Department of Agriculture, Soil Conservation Service, Washington, D.C.

Here a soil sample is taken of land on which corn has been grown since 1931. The sample will be examined under a microscope in the laboratory. Why do you think such samples are taken?

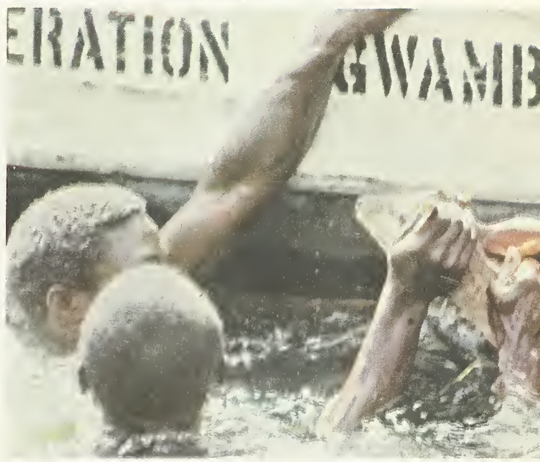
A gauge to record rain, snow, hail, or sleet is adjusted. The information gained from such gauges is necessary for flood control.

Snow surveys measure how much water runs off the mountains when the winter snow pack melts. This information is needed to predict floods or droughts, to plan for water storage, and to use for irrigation and hydroelectric power. Snow measurements are made by sampling snowfields with a hollow aluminum tube.

The aluminum tube and the snow sample it contains are weighed. From this figure is subtracted the weight of the empty tube. This figure is changed mathematically into inches of water in the snow, and is used to forecast runoff and stream flow.

Snowfields are measured in exactly the same location each time. The location is called a snow course. Why do you think repeat measurements are made year after year in the same place?

You have seen and read about only a few of the activities of the United States government's program in conservation. Use your school or public library to find out more. You will be surprised to find out how many people work at conserving wildlife, land, and water.



There are other groups also working to save animals from extinction. In 1964, when thousands of miles of forests were being flooded by the new Afobaka Dam on the Surinam River in Surinam, South America, a project called Operation Gwamba was begun. Gwamba comes from a phrase in the language of the jungle people meaning "Pity the poor animals." Both the Surinam government and the International Society for the Protection of Animals supported Jan Michels, a Dutch district commissioner, and John D. Walsh, an officer of the Massachusetts Society for the Prevention of Cruelty to Animals, in their project.

Sloths, ocelots, boa constrictors, howler monkeys, and other animals were lassoed from trees or taken from the water. Traveling in canoes and wearing heavy gloves for protection, the two men and about twenty-five helpers, armed with poles that had nooses on the ends, pulled down the animals trapped in the treetops. The animals were tied up with old nylon stockings and then released on the shores of the rising lake.

In Rhodesia, Africa, government game rangers have launched a program to save rhinoceroses from death. Many of the animals have been captured and taken 260 miles on a rough wooden sled to Rhodesia's Wankie Game Park, where they will be protected.

These are just a few of many examples of the efforts of various governments, societies, and individuals to protect living things from extinction. To let any species of plant or animal vanish is to lose for all time a part of our inheritance. The plants and animals alive today are the ancestors of all the plants and animals there will ever be. Extinct species are gone forever and, with them, the offspring they would have had.

You read about the discovery of penicillin when you studied diseases. Until its discovery, few people, including scientists, gave much thought to the fungus organisms living in the soil. Now these organisms are being studied in hundreds of universities, government agencies, and industrial concerns as possible sources of drugs to aid human health. This is an example of how a little-known species of plant can become a valuable contribution to the world. The condor, the whooping crane, the rhinoceros, and the fungus organism are all living resources. It is important for man to protect them. Man's nonliving products can all be replaced, but man can never replace extinct species of living plants and animals.

While many people are aware of what is happening, few do anything about it. Man has a choice: He can conserve his living resources so that they provide a continuing harvest, or he can exhaust them and endanger his own survival. In the years to come, you will have something to say about the choice that must be made.

Conserving Human Resources

You are a resource. Every human being is a resource.

Today polio, smallpox, and other diseases need no longer destroy human lives. Yet many people have diseases that could easily be cured if they were treated by doctors. These diseases make them unable to do any work. In other parts of the world, people lack the skills needed to make enough money to eat properly. In many areas, thousands of people live cramped together in rooms or shacks without water, electricity, or toilets. Tens of thousands of people are unable to use their abilities to their fullest because of the conditions into which they were born. All these people might have something to contribute to our world, but they are unable to. Of all our

resources, human resources are our most precious.

In conserving human resources we must deal with the problems of poverty and ignorance and the danger of using up our resources of food, fuel, living space, and privacy. When any of these resources is inadequate, human energy that might produce great works of art or scientific discoveries is diverted to the problems of day-to-day survival.

In some places, people live cramped together in shacks or boats. They are underfed, poorly clothed, diseased, and unskilled. How might they be helped?

These boys and girls come from many states. They are all winners in a Science Fair contest. They may not all become scientists, but they all understand the importance of science in today's world. Why is this important?

William Vogt, a conservationist, compares the growth of human population with the human pulse rate. If you count your pulse for a few seconds, it will not quite keep up with the increase in world population. Each time your heart beats, more than one human being will have been added to the population of the world. In the past fifty years, the population of the world doubled.

With more people living on the earth, more food, more clothing, more houses, and more forms of transportation are needed. Thus, more of the earth's natural resources are used up.

To conserve our human resources, scientists must find ways to obtain more water, use the soil to greater advantage, and find ways to farm the seas, among other things.

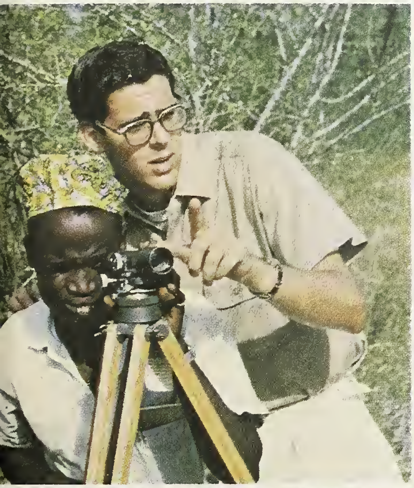
Brainpower has been called our most precious national resource. How well we meet the problems of tomorrow's world depends on how well we discover, encourage, and develop exceptional talent in all fields. The talent of the scientist and the resources of the educated person who can recognize the importance of science for other fields, such as medicine, military affairs, industry, law, and politics, must be conserved.

Teachers and others who work with young people must encourage and guide those who show promise. They must help them seek and obtain the goals for which they are best suited. People are learning to respect intelligence. No one can tell how great a contribution an intelligent person can make.

The guidance counselor helps this girl decide what kind of training she will need for the career she has chosen.

Conservation and You

The world of tomorrow depends on what we do today. If we waste our resources the world may be barren for those who follow us. But if we care about tomorrow we can use what we know to make this a world of plenty. We know much about conserving wildlife, soil, water, and forests. And we know much about conserving human life. All are related. Each depends on the others. Although there is still much to be learned, we know enough now to do something, and we know we must do something. The choice is up to every one of us.



We can send food and clothing to help people. Perhaps, more importantly, we can send trained people to help them learn modern ways of building, working the land, and preparing foods. We can train doctors, teachers, carpenters, and plumbers. In these ways, we can help these peoples to help themselves.

Using What You Have Learned

1. Make a list of all the different kinds of animals you can find in an empty lot near your home. What happens to each animal when a house is built on the lot?

2. Make a plan for helping other children in your school find out about the usefulness of wildlife. What different kinds of posters could you make? What kind of talks could you give? Could you write a short play about wildlife for an assembly program? Your class might prepare an exhibit on the usefulness of wildlife.

3. Find out from some of the people who have lived in your community for many years what animals used to be more common where you live. What has happened to these animals?

4. Why should everyone not be allowed to use the wildlife that lives on his own property in any way he wants to?

5. What are some of the hunting and fishing laws in your state? Discuss the reasons for these laws.

6. Write to your State Conservation Department. Ask for pamphlets about animals that are protected in your state. Find out how these animals are protected. Is your State Conservation Department trying to cut down the number of any animals? Why?

7. Look up one of these subjects and report about it. You may have to look in several different books.

a. The use of bird feathers for ornaments
b. How railroads affected bison
c. How building dams on certain rivers has affected our supply of salmon

8. If you live in a farm region, ask some farmers about the

crop rotation plans being used locally. Find out why they use this particular method.

9. Make a map showing the sources and location of various types of water pollution in your area. Find out from county, city, and state officials what is being done to decrease pollution. Make a sand table model to show how water pollution occurs.

10. Take a census of trees along the sidewalks in your community. Since you may not be able to count all the trees, do it this way. Have each pupil in your classroom count the number of trees of all kinds there are along the block where he lives. Next, figure out the number of tree-lined blocks in your community. Now can you figure out how many trees there are along the walks in your community?

11. Explore an empty lot or field near your school to find out what food wildlife of different kinds could find there. Look for seeds and for insects, worms, and other small animals. If you live near a woods, explore it in the same way. Compare the woods and the empty lot as wildlife refuges.

12. Theodore Roosevelt did much to protect wildlife when he was President. Read what he did in a biography of his life or in an encyclopedia.

13. Find out what your community is doing about air pollution.

14. Discuss with your class why we cannot afford to waste human resources. Find out what your community is doing to conserve human resources.

15. Write a report on John James Audubon, whose 435 paintings are known the world over for their naturalness and accuracy.

16. Find out why Alexander Wilson is known as "the father of American ornithology."

WHAT YOU KNOW ABOUT

Life on the Earth

What You Have Learned

All living things get food from green plants or from animals that eat green plants. Green plants take in water, carbon dioxide, oxygen, and minerals. They use light to change these substances into glucose by the process of photosynthesis, which takes place in the parts of the plant cells called **chloroplasts,** which contain the green chemical **chlorophyll.**

Some plants help make soil. **Lichens** are plants that grow on rocks. They use oxygen and give off carbon dioxide, which combines with water to form **carbonic acid.** This acid slowly eats into the rocks and makes cracks in them. Roots of lichens and mosses grow in the cracks of the rocks and split apart the rocks to form the soil.

There are different kinds of regions on earth—deserts, mountains, grasslands, and forests. Each has its own kinds of plant and animal life best adapted to the environment in which they live.

When environmental conditions change, the animals and plants must adapt themselves to the new conditions or die. Some animals adapt to winter by **hibernating.** Other animals **migrate** to a warmer place for winter.

There is a natural balance or interdependence among all living things. Whenever the natural balance is upset, some living things die. **Predators** are animals that attack other animals for food, creating a natural balance of life between two or more different animal populations.

Man sometimes upsets the balance of nature. To preserve the natural balance of life, man must carefully provide for the protection and **conservation** of the earth's resources.

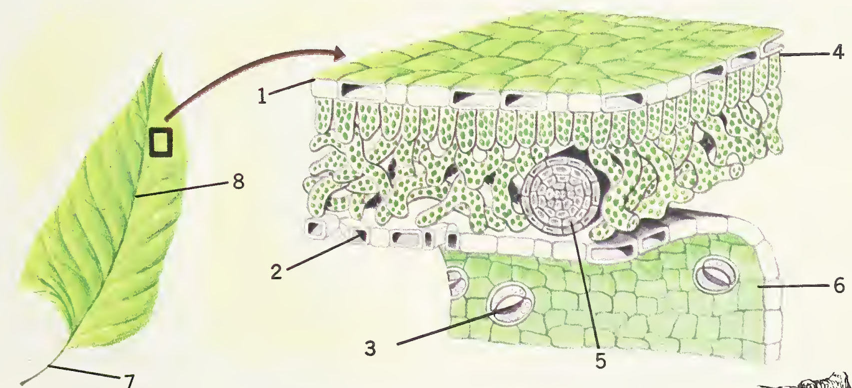
Checklist of Science Words

Here are some science words you read about in this unit. Can you tell what you have learned about each one?

biochemists	extinct	predators
carbonic acid	hibernation	protective coloration
chloroplasts	migration	smog
conservation	pollutant	stomata
epidermis		

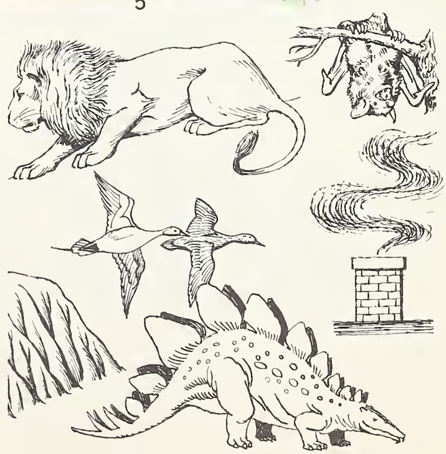
Can You Identify the Parts?

Look at the diagram of a green plant. In your notebook write the numbers 1 through 8. Next to each number write the name of the part shown.



Fill in the Missing Letters

This animal is a p________.
This animal h___________ in the winter.
This animal m________ in the winter.
This air is p________.
This soil is e______.
This animal is e_______.



YOU CAN LEARN MORE ABOUT

Life on the Earth

You Can Visit a Biome

A biome is a community of living things that depend on one another for survival. A good biome has a variety of land forms and different kinds of plants. A biome may be a forest, a pond, a desert, an open field, a meadow, or any other natural environment.

When you visit a biome, answer these questions:

1. Where do you find various plants?
2. Where is there water?
3. Which areas get the most sunlight?
4. Which areas get the least sunlight?
5. What does the amount of sunlight have to do with the location of the plants found?
6. How do the plants affect the temperature?
7. What relationships do you find between plants and kinds of soil?
8. Do you find any eroded land?
9. What signs do you find of animal life?
10. Do you find any animal life living on plants?
11. How do these animals differ from animals that do not live on plants?

You Can Make a Biome

Fill a three-gallon bottle halfway with pond water. Then add about ten ounces of soil and some algae from a pond. When the water is clear, add five sprigs of elodea. Next, place a guppy, a snail, and a piece of clamshell in the bottle. Place it in a well-lighted part of your room, but not in direct sunshine. The temperature should not rise above 70° F.

1. How does this biome show the interdependence of the plants and animals in it?
2. How does each organism get the food it needs?
3. How do the animals get their energy?
4. How do the plants get the energy they use in photosynthesis?
5. How do the plants get the energy for their life processes other than photosynthesis?

You Can Read

1. *The Tale of a Pond,* by Henry B. Kane. Describes a cycle of life in a pond.
2. *The Web of Nature,* by Ted S. Pettit. A description of various kinds of environments and the need for conservation practices.
3. *The First Book of Conservation,* by F.C. Smith. Discusses the interdependence of living things, how man has upset the balance, and practices to conserve our natural resources.



8

How Animals Behave

Observing Animals

Animal Sense Organs

Explaining Behavior

Is Animal Behavior Inherited or Learned?

There is a legend that King Solomon had a magic ring. With it he could speak to animals. He could understand them and, in turn, be understood by them. You need not have a magic ring to understand living things. You can learn about them by observing and studying the ways in which they behave.

Observing Animals

When your parents talk about your behavior, they usually mean something you did that was good or bad. When a scientist talks about behavior, he means all the *activities* of an animal except those that it is born with and that are automatic, like breathing. Have you ever turned a beetle or an ant from its path as it marched along a tree trunk? Did you observe what it did to find the path again? You were studying the beetle's or the ant's behavior. Scientists study animal behavior to try to explain how and why animals do what they do.

If you drop some food into an aquarium, a hungry fish will go after it. Notice that the fish does not swim around in circles searching for the food; it swims directly to it. Try fooling the fish by dropping something into the tank that looks like fish food but is not, and you will see the fish swim away from it. Some people explain the fish's behavior by saying, "It was born that way," or, "It can think and figure out the difference." But animal behavior is much more complicated, as you will see.

To start your study of animal behavior, you must observe animals carefully to see exactly what they do. If you have a pet at home, you can start by observing its behavior. You can also observe the birds and squirrels in your backyard or park. You can find insects for study almost anywhere, both inside and outside.

Snakes, frogs, and toads are easy to catch. Search the ponds and streams near your home for fish and other water animals. Catch some with a net and bring them to your school or your home for study.

If you live on a farm, you will have many opportunities to observe animals. Finding an animal to study should be easy for everyone.

Birdwatching is for both young and old. Studying the behavior of birds will give you many hours of pleasure and may develop into a lifetime hobby.

Describing Behavior

When you first try to observe animal behavior carefully, you may find that you have never *really* looked at what an animal does. You know that your dog or cat or hamster eats, moves about, makes noises, and has some funny habits, but chances are that you have not really noticed its behavior.

Scientists who study the behavior of animals are called **ethologists** (eh-THOL-uh-jists). An ethologist is curious about every detail of behavior. To organize his study, he classifies the many different kinds of behavior under headings such as "food-getting," "fighting and escape," and "moving about." He wants to know why an animal eats what it eats and when it eats. He wants to know what an animal will do if a stranger approaches. He is curious about how an animal finds its way and why it does not lose its way. He may study an animal in its natural environment, or he may bring it into his laboratory.

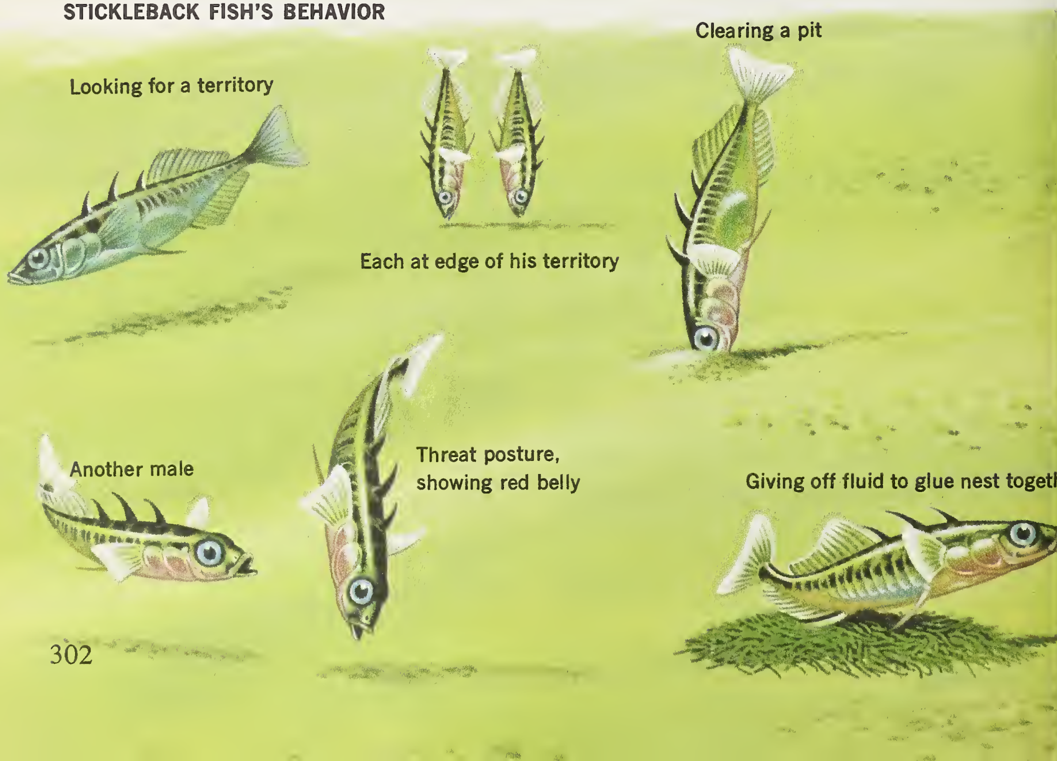
As the ethologist observes, he searches for clues that will lead to ideas that will help him to describe and explain behavior—ideas that will explain many different situations. These are *key* ideas. The fact that your dog barks every time the doorbell rings is not really a key idea; it does not explain very much. On the other hand, the ethologist, for example, is interested in explaining what makes animals ready to fight and why they are more ready at some times than at others. He is not satisfied to know simply *that* they fight. How do you think the ethologist goes about his work?

To find the key ideas about fighting behavior, the ethologist can start with almost any animal that can fight. He knows from previous research—his own and the research of others—that certain things will be true of all fighting animals, even though the *details* will be different. A dog fights differently than a cat, but some things about their fighting are the same.

Observing the Behavior of the Stickleback Fish

One animal whose fighting behavior has been studied in the search for key ideas is the stickleback fish. This is

STICKLEBACK FISH'S BEHAVIOR



a rather common fish. If you have ever caught this fish with sharp, spiny sides, you know that it is a fighter. The stickleback not only is a fighter at the end of a fishing line; it is a fighter in the water, too. Thus the stickleback fish is a good subject for the ethologist to study.

As the scientist observes the stickleback, he finds that it is the male that fights. But even the male stickleback does not fight all the time, and he fights more fiercely at some times than at others. After more observations, it is found that the stickleback does most of his fighting right after he has built his nest. This is also the time of his fiercest fighting. If a stranger comes close to his nest, the male stickleback fish charges with great speed and fury. He fights even if the stranger is much larger than he is. He extends his spiny sides and dashes at the enemy, chasing him away fast and furiously.

The ethologist uses other information to help him understand the behavior of the stickleback.

Knowing that fighting is related to nest building, the ethologist records observations when the stickleback starts building his nest. He finds that the stickleback builds himself a nest at the

bottom of a pond by first scooping out a pit in the sand. He carries the sand away a mouthful at a time until the pit is hollow enough. Then he puts weeds on top of the pit and shapes them into a mound. In this mound, he makes an opening which will be the nest itself.

When the nest is finished, the fish, once a dull gray, changes color! His sides become a glowing red, his back a shiny blue-green, and his eyes bright green. It is at this point that his behavior also changes. He protects the nest and drives off any *male* stickleback that comes near.

How far from the nest will the fish fight? Ethologists have observed that the fish has a *territory* that he defends. The nest is the center of the territory, and the stickleback will fight only within a certain area around the nest. He will chase away any strange fish that crosses the unmarked border. The closer the stranger comes to the nest, the more fiercely the stickleback fights. At the nest, he charges furiously at any intruder without any regard for his own safety. The stranger will flee to his own territory, with the stickleback in swift pursuit. Then, as the stickleback swims farther from the nest, he loses some of his fury and charges with less energy. Once they are over the border and in the strange stickleback's territory, the stranger becomes the fighter! He turns on his chaser and drives him back across the border. Back and forth across the border they go, taking turns at being the chaser and the chased.

There seems to be a point, however, where neither one attacks. At this point each fish still extends his spiny sides toward the other in a threatening way, but neither one dares to charge. Instead, they dig frantically at the bottom of the pond, exactly as they did when they were nest building! In this way, they get rid of their fighting spirit. If each stays on his side of the border, the fight is over.

The Search for Key Ideas

Can you find some ideas in these observations that *might* describe not only stickleback fighting behavior, but the fighting behavior of other animals as well? List some of these ideas.

The ethologist studies his observations and tries to draw from them some key ideas about animal fighting. He searches for ideas that he can test on other animals. One such idea is that the closer a stranger comes to the center of an animal's territory, the fiercer the animal becomes.

Is this true of other animals, too? Let us see how a dog behaves when an enemy moves into his territory. How do two male dogs behave when they

meet on the street? They become stiff-legged, their tails go erect, and their hair rises. The closer they come to each other, the slower and more careful their movements become. They pass each other side-to-side, head-to-tail, and then begin to sniff each other's hind regions. The sniffing may go on for quite a while and end in friendly tail wagging. But it may also end with lips curled back to show the fangs, deep growls, hind feet scratching the ground —and finally a fight.

Can you find ways in which the fish and the dog are alike in their fighting behaviors? Is it true that each is fiercer the closer the enemy is to his territory? What is the center of the dog's territory in this case?

The ethologist finds other key ideas in his observations of the stickleback's behavior that he can apply to the behavior of other animals. Compare the list you made with this list made by the ethologist.

1. Male animals set up and defend territories around their homes.
2. The closer a stranger is to the center of the territory, the more fiercely the male defends his territory.
3. The closer it is to mating time, the more fiercely the male defends his territory.
4. The border of a territory can be defined as the place where two males seem to be about equal in fighting spirit.
5. When an animal wants to attack but dares not, he may get rid of his fighting spirit by turning to some other activity.

Using What You Have Learned

1. Review the description of the stickleback's fighting behavior. Find examples of each key idea listed above.

2. If you have a male dog, look for signs that he has a territory. What clues does he give you as to where that territory ends? Compare your findings with those of classmates who have female dogs. Do females stake out a territory?

3. All of the fighting behaviors described so far are connected with *territory*. Do two animals ever fight each other when neither one is in his own territory?

4. One key idea says, "The closer the stranger to the center of an animal's territory, the more fiercely the animal defends his territory." In the statement, distance from the center is one factor and fighting spirit is the other. The statement shows the relationship between the two factors. A statement of this kind in which one factor is said to increase as the other factor increases describes a *direct proportion.* In science you will find many relationships stated as direct proportions. As one factor gets larger, so does the other. Scientists look for relationships between factors.

Does the fighting spirit of the male change in direct proportion to any factor other than the territory? What is the relationship?

5. How do animals differ in the way they eat? Have half the class observe and take notes on the feeding behavior of a dog, and the other half on that of a cat. Each pupil should write down what the animal does as it approaches the food, how it eats, and what it does as it finishes the food. Compare observations of the dog and cat. How are they alike? How are they different?

Compare observations of different breeds of dogs. Are they alike? Are they different? How? Which are greater, differences between breeds or differences between species?

6. Here are some other behaviors of animals which you might observe: moving about, courting, nest building, taking care of the young, and signaling. ("Signaling" behavior means all the ways in which animals communicate with one another. For example, when a stickleback extends its spines along its sides, it is signaling to an intruder that it is in a fighting mood.) Choose one kind of behavior and observe and take notes on one kind of animal. Compare your observations with the observations of classmates who have studied a different animal's behavior. Search for key ideas. Test the ideas to see if they apply to many animals.

Animal Sense Organs

You have been learning about the search for key ideas that describe animal behavior. These ideas also help to predict behavior. For example, they help to predict when an animal will have the most fighting spirit. Perhaps from your observations you have discovered an idea that helps to predict what will happen when an animal wants to do two things at once—like eat and fight!

You have seen that the stickleback does some very remarkable things, but you still do not know how or why. We have not as yet *explained* behavior. To understand the how's and the why's, we have to examine the animal further.

We know that the stickleback makes a choice between running and fighting. We know that the choice depends on his nearness to the nest. But how does the stickleback recognize when he is near the nest? How does he know when he reaches the border of his territory?

What an animal does depends in part on the information he has about what is going on around him. The sights, the sounds, the smells—all inform him about what is happening. His **sensory** equipment brings him information. To explain animal behavior we must find out about this sensory equipment.

Sensory Receptors

You have sense organs, such as eyes and ears, which bring you certain kinds of information. However, there are some things that you can sense without a special organ. For example, you can sense a change in temperature. This is because your skin is equipped with sensory receptors for heat and cold.

Sensory receptors receive information. Each kind of sensory receptor receives only one kind of information. You do not smell with your ears or feel with your eyes! An animal that does not have sensory receptors for smell has no sense of smell.

Not all animals have sensory receptors. The simplest animals, like the ameba, have only one cell to do many different jobs. However, this one cell is still somewhat sensitive to its surroundings. For example, when the ameba is ready for food, it can tell the difference between a grain of sand and a bit of seaweed. But with such limited sensory equipment, the ameba can take in only a very limited amount of information.

Sensory receptors are made up of **cells.** All living cells can be stimulated. Apply the form of energy to which the cell is sensitive, and there is a reaction in the cell. For example,

when heat energy from a stove stimulates certain cells in your fingertips, something happens inside the cells. When you eat a hamburger, chemicals in the hamburger stimulate the cells for taste in your mouth. Something happens inside those cells. *In each case, it is in the cell that something happens.*

Scientists group sensory receptors according to the *kind* of stimulation each can receive. Let us study some of these receptors in detail and see what key ideas can be formed about animal senses.

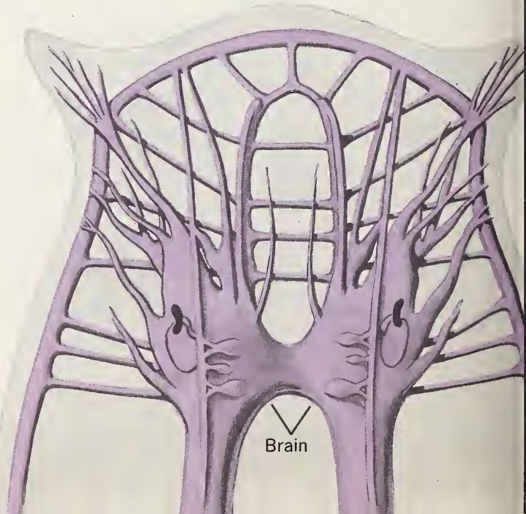
Chemical Receptors

Receptors that are stimulated by chemicals are called **chemoreceptors** (kem-oh-rih-SEP-terz). Some chemoreceptors help us to taste and to smell. Chemoreceptors are very important to animals. They help many animals to survive. Some animals can "smell" danger.

The chemical senses of some animals are much more sensitive than our own. This is especially true of the sense of smell. The fish has a well-developed sense of smell. You remember that the male stickleback chases off other males. However, if a female enters his territory, the male may do a zigzag dance, which is his way of inviting the female stickleback to enter the nest and deposit her eggs.

How can the stickleback tell the difference between a male and a female? A female gives off different chemicals from a male. You know that the water in which cabbage is cooked smells different from the water in which asparagus is cooked. Each vegetable gives off different chemicals. Our sense of smell is sensitive enough to pick up such great differences in smells, but not very small differences. Fish have receptors for smell that are sensitive even to the tiny bits of chemicals given off by another fish as it swims by. These receptors are all over the fish's body.

Even worms are sensitive to chemicals! Planarians (pluh-NAIR-ee-unz) are small flatworms that live in water. They crawl along the bottom of streams. As food dissolves in water, it gives off chemicals. As the worm gets near the food, the food chemicals stimulate receptors on the worm's head. The worm's head moves from side to side.

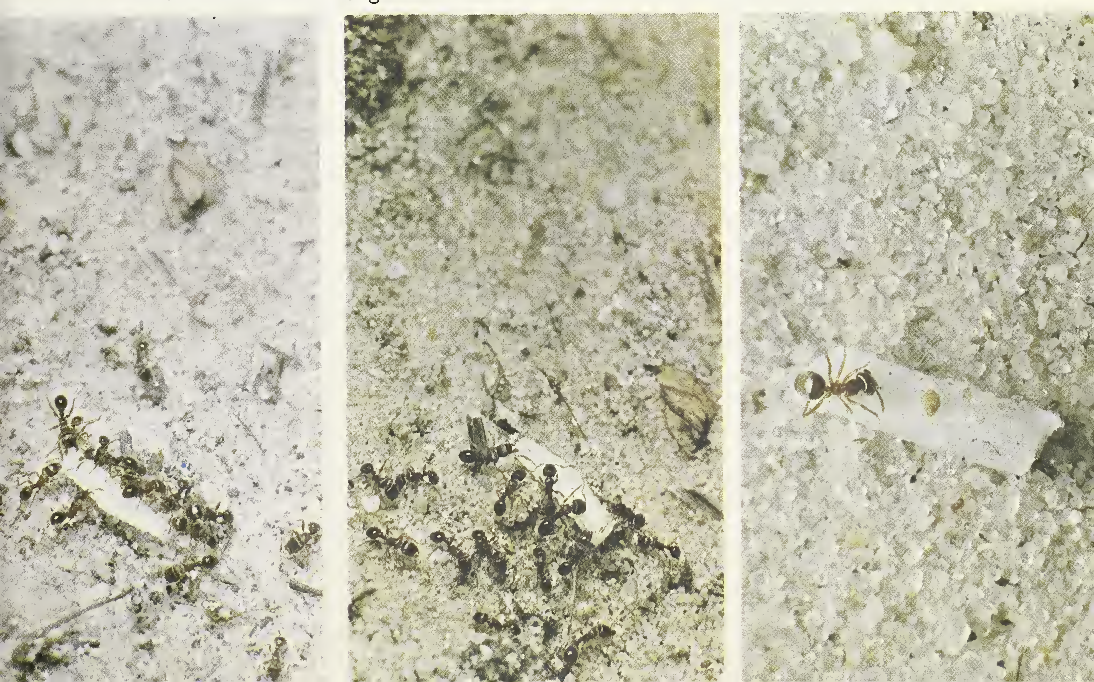


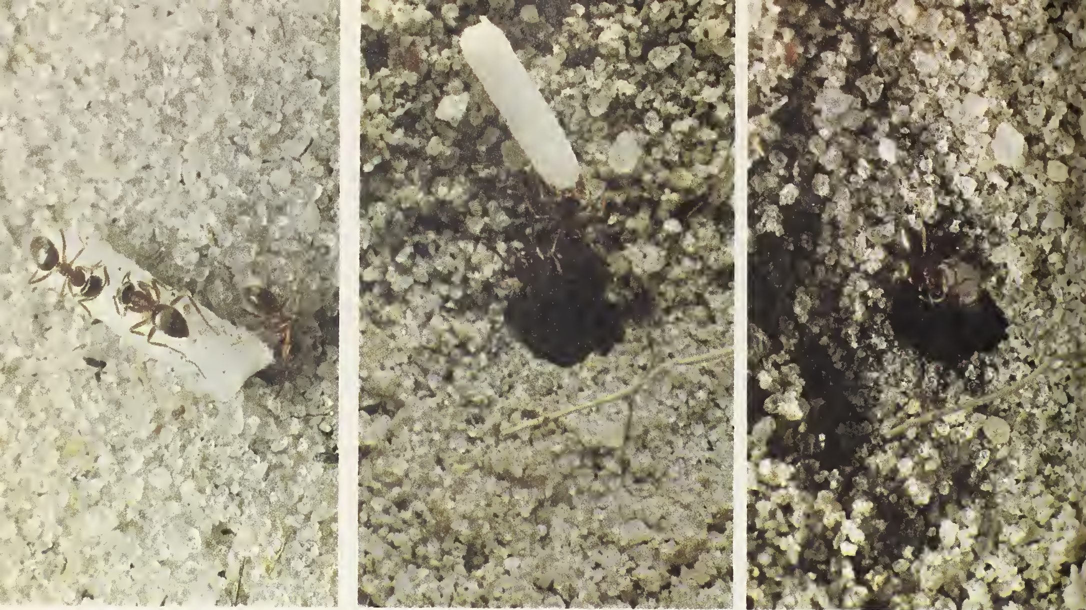
The receptors receive more stimulation as they approach food. The worm moves in the direction of the greater stimulation.

If someone were cooking hamburgers, you might find out where the smell of hamburgers was coming from by sniffing the air. Since more chemicals are in the air near the fire, your sensory receptors pick up this information. Even blindfolded, you could find the hamburgers.

Have you ever watched ants at work? Ants are **social insects.** Thousands of ants live together in a colony, and each kind of ant has a special job to do. There are scout ants, whose job it is to search for food, and worker ants, who must bring the food to the queen and to the young in the nest. The ant's keen sense of smell helps it to carry out its special job. Have you ever watched ants at a spot where sugar has been spilled? First you see only a few stray ants, the scouts, who explore. The scouts report back to the workers, and soon a column of ants, four or five wide, descends on the sugar. To reach the sugar they follow the same path that the scouts used. Each picks up a crystal of sugar and carries it back to the nest to feed the young larvae. On the return trip, the ants keep to the same route that they followed to find

Can you follow the pictures below and on page 310? They show the behavior of ants who have found sugar.





the sugar. The workers go back and forth without wandering from the path.

How do scientists explain such behavior? How does the ant keep to the path? Scout ants leave a chemical trail for the workers to follow. As they move across the ground, they squeeze out tiny bits of chemicals from their intestines. The chemicals form a path with a distinct odor picked up by the senses of the workers. The ant does not have a nose, but it does have receptors for smell in its antennae and can sense the odor trail. As the food supply dwindles, the ants leave fewer and fewer bits of chemicals. The odor trail disappears when there is no more food.

Taste is another chemical sense. Insects have receptors for taste that they use in selecting food. These receptors are stimulated only by certain substances and not by others. Did you ever wonder why some insects eat only a certain kind of plant? The silkworm, a moth larva, is attracted to mulberry leaves; the potato beetle, to the potato; the corn borer, to kernels of corn. The chemicals in each of these substances stimulate the insects' taste receptors. Most insects feed on only a few kinds of plants and cannot live on others. Their taste receptors are so specialized that they are not stimulated by certain things that are food for other animals.

Does Light or Smell Enable an Ant to Find Food?

What You Will Need

ant colony	table	sugar
glass jar	metal rail	

How You Can Find Out

1. You can get an ant colony from a biological supply house, or you can dig for one. Be sure that you get the whole colony, including the queen. Be sure also to use sugar ants. The sugar ant is a small, dark-brown insect.
2. To make sure you have the right kind of ants, sprinkle some sugar near the colony and observe the ants before digging.
3. Put the colony in a large, covered glass jar with tiny holes in the cover for air.
4. Make a metal rail around the table, with slippery sides that the ants cannot climb.
5. Remove the cover, turn the jar on its side, and put sugar at the other end of the table.
6. Observe and record what the ants do as they set up a trail.
7. Block off light on one side of the table. Observe and record any changes in the ants' behavior.
8. Rub your finger across the trail in front of the ants as they run toward the sugar.
9. Observe and record any changes in the ants' behavior. Try different-sized breaks in the ants' trail.
10. Record what happens as the sugar supply diminishes.

Questions to Think About

1. Which receptors are the ants using to find the way?
2. Would their chemical receptors work for foods without sugar?
3. How can you figure out from how far away the ant's chemical receptors can sense a substance?

Photoreceptors

Another group of special sensory receptors is **photoreceptors.** The Greek word *phos* means light. Can you guess the kind of stimulation to which photoreceptors respond?

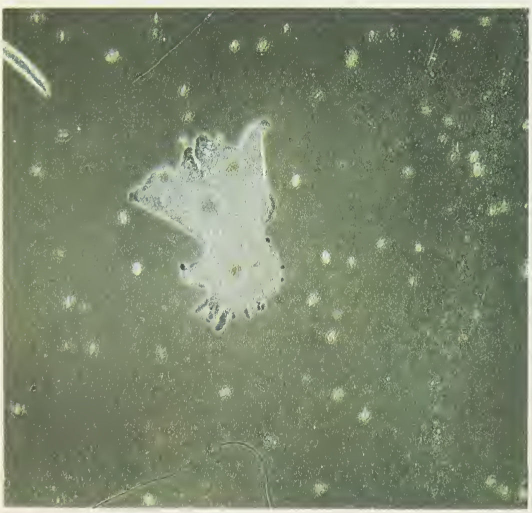
Almost all animals are sensitive to light and will react to differences in brightness. One-celled animals have no special organ that is light-sensitive, but even these animals will move away from a very bright light.

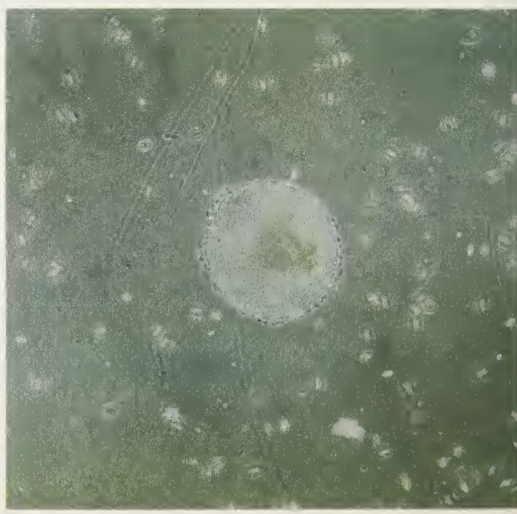
The euglena has a bright red spot, called the *eyespot,* that scientists believe is part of a light-sensitive apparatus. The special eyespot of the euglena is more sensitive and so better able to detect light than the protoplasm of the ameba, which also reacts to light. This specialization is important since, as you may remember, euglenas depend on photosynthesis for their food. It is to their advantage that they expose themselves to the light as much as possible.

The planarian has two eyes, which are sense organs specialized to react to light. Each eye consists of black pigment filled with special cells whose ends continue as nerves that enter the brain. Planarians avoid light and are usually found in dark places, under stones or the leaves of water plants.

Higher animals have special cells that are sensitive to light. The earthworm has light-sensitive cells at either end; the end regions are most frequently exposed to light.

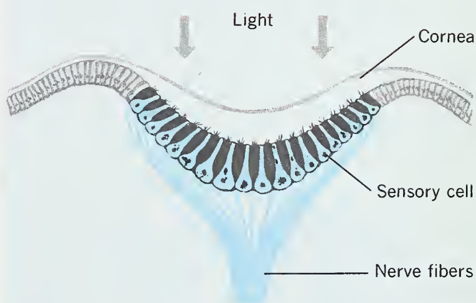
Although the ameba has nothing that can be compared to our sense organs, it does flow away from bright light and pull itself into a rounded shape, as you can see below. On the left is the ameba before a bright light is shone on it.





If you shine a flashlight on an earthworm, it will disappear into its burrow. A large part of the earthworm's body —not only the ends—is sensitive to light. Find an earthworm and see for yourself.

It took a long time in the history of animals for the eye to develop. The eye is a special kind of photoreceptor. The simplest "eyes" in animals are only colored, cup-shaped tissue. This tissue is made of cells connected to the brain by nerves. As eyes become more complicated, a lens appears that makes it possible for an animal to see some patterns. With additional parts, the eye can form an image. Look at the diagram on page 314 of an image-forming eye. Can you tell what happens as light enters it and stimulates the cells? How is the image formed?



SIMPLE EYE

Animals with backbones (vertebrates) have image-forming eyes. Sometimes such eyes are called camera eyes. Can you explain why?

All camera eyes have the same kinds of parts and work according to the same principles. However, they are not exactly the same in all animals. There are differences that are related to the animal's way of living. Some animals have more rods in the retina than other animals. Rods are especially sensitive to light and can be stimulated even by very little light. Such animals often have a slit pupil instead of a round one. The slit pupil can open wider and thus allow more light to enter the eye. The way the eye is made is related to how it works. With such an eye, an animal can hunt when there is very little light. Can you name some animals that hunt at night?

Other differences make it possible for the eye of an animal to adjust to size, shape, pattern, color, and distance. Birds, such as swallows, that feed in flight have *two* areas at the back of the retina where vision is sharpest; other animals with camera eyes have only one such area. These two areas can register a great deal of information from a very wide angle. A swallow can see and capture in flight a juicy insect way off to the side of the eye. What other animals have good side vision?

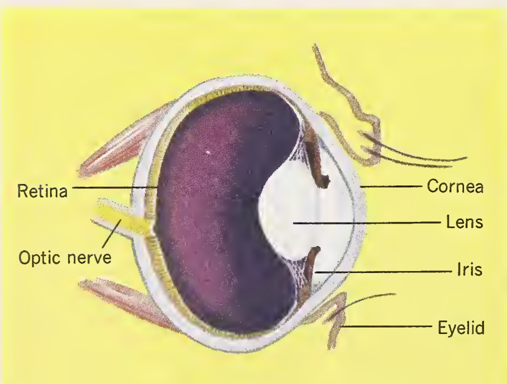
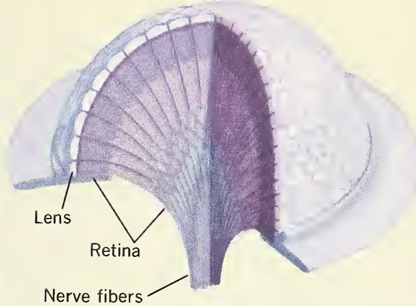


IMAGE-FORMING EYE

What is the shape of the pupils of the cat's eyes? How does this shape help the cat see when there is little light?



MOSAIC EYE

The insect has a mosaic eye made up of many small units, each unit with a small bundle of light-sensitive cells and a lens. The mosaic eye does not give as sharp an image as the "camera" eye of man gives. However, some insects' eyes probably form very good images—these insects have been seen trying to get nectar from the flowers on wallpaper.

Insects have **mosaic** (moh-ZAY-ik) eyes. These are made up of separate **facets** (FASS-its), or small surfaces, like those you see on a diamond. Beneath each facet are light-sensitive cells. These facets serve as lenses to gather light. Because each facet is separate from the others, the light-sensitive cells of each one can be stimulated separately. Since light has a wave motion, waves go out in all directions from any light source. However, mosaic eyes do not pick up all the wave motions. As light enters each facet, only some of its waves pass through. Each facet in the mosaic, then, registers a different pattern of light and dark.

Insects make use of these patterns to find their way. Their eyes do not register a clear image of an object, as man's eyes do, but insects are very sensitive to the movements of objects around them. Any movement changes the amount of light falling on one of the facets, and so the slightest motion of enemy or prey is quickly detected.

EXPERIMENT

Can Some Insects See Differences in Color?

What You Will Need

sugar solutions   vegetable dyes of different colors   boards

How You Can Find Out

1. Make some sticky sugar solutions of different colors using the vegetable dyes.
2. Paint the solutions on the boards, using a different board for each color.
3. Prop the boards against a tree trunk and leave for 24 hours.
4. Collect the boards in the morning and count the insects trapped on each solution. Record.
5. Repeat for several days, recording each morning.

Questions to Think About

1. Based on your records, can you write a concluding statement about whether or not some insects can see differences in color?
2. How does being able to see colors help an insect survive?

Thermoreceptors

Another group of receptors is called **thermoreceptors.** The Greek word *thermos* means heat. Thermoreceptors are sensitive to changes in temperature. Being able to detect temperature is important to an animal. An animal will die if the temperature is too high or too low. There are cold-blooded animals, such as snakes, whose body temperatures change with the changes in the outside temperature. But even they can survive temperatures only within a certain range.

An animal must be sensitive to temperature change. Its body carries on its work best in the temperature suited to it. The polar bear thrives in temperatures too low for the elephant. The thick fur of the bear is an excel-

lent insulator. Fur can also insulate against heat, but not always enough. Fur seals, for example, cannot stand warm weather. If the temperature of the water in which they live goes much above 50° F., they will die of overheating.

All animals can get used to some temperature changes; they become **acclimatized** (uh-KLY-muh-tyzd). That is, they adjust to different climates. They can only do this, however, within certain limits. These limits are set when they are born.

Animals seek out places around themselves where the temperature is most favorable to them. Watch how your dog will move about on a hot day, seeking a cool spot. Or perhaps you have noticed how grasshoppers seek out a hot, sunny place in which to bask. The animal in each case does not think, "I'm too hot," or "I'm too cold; I'd better move." But activity within the cells of its body changes with the temperature.

If an animal is too hot, its body acts to get rid of heat. Evaporation is one way to cool off the body. Animals that sweat or pant lose water by evaporation, and their bodies are cooled. In the opossum and some rats, saliva flows freely on a hot day. These animals lick their fur. The water evaporates and cooling results.

Changes in blood vessels also help to get rid of heat. Blood vessels near the skin get larger when the temperature goes up. More blood flows into them. The more blood near the surface of the skin, the more heat that can be given off from the body into the air. Will hot soup cool more quickly in a cup or in an open dish?

There are more ways in which animals can adjust to cold. Some animals hibernate. In hibernation the animal's body usually remains at about the same temperature as the outside air. As its body temperature goes down, its heart also slows down, and less oxygen is taken in. Some animals, like the hamster, will wake up when the air temperature drops dangerously low. But if its temperature receptors are not working properly, the animal will die in freezing temperatures.

How does licking its fur keep the opossum cool on a very hot day?

There are still other adjustments that an animal makes to low temperatures. It may shiver, as we do. This movement produces more heat in the body and saves what heat it has. Blood vessels in the skin become smaller, so less blood is near the cold air. Hairs or feathers may stand up on end. An animal may cross its legs or shrink up so there is less skin exposed to the cold air.

Bees have a very special way of keeping the temperature in the hive from dropping too low in winter. Tens of thousands of bees may cluster together in a hive. When those on the outside of the cluster get cold, they flap their wings and move their feet. Their movements make bees in the next layer active. The activity spreads until all the bees are flapping their wings and moving their feet. What happens to the body temperatures of the bees as they move about? What happens to the temperature of the air inside the hive?

Next fall, record what various animals in your community do to prepare for the cold weather.

A little brown bat hibernates when the temperature goes down. How does this help the bat to survive during the winter months?

How are these bees raising their body temperatures? What happens as their body temperatures rise?

Mechanical Receptors

Still another kind of receptor receives stimulation from touch, pressure, and sound. These **mechanical receptors** are sensitive to forces pushing against them. They serve as receptors of physical changes in the surroundings. Some insects have small bristles on the surfaces of their bodies. There are receptors where the bristles are joined to the surface that can pick up information about what the insect is crawling over. The bark of one tree would push against the bristles in a very different way from the bark of another tree. As this information reaches the nervous system, changes may occur in the animal.

EXPERIMENT

Do Ladybugs Prefer Rough or Smooth Surfaces?

What You Will Need

ladybugs tree bark smooth board

How You Can Find Out

1. Set up a runway with the tree bark at one end and the smooth board at the other.
2. Start the ladybugs on the rough surface. Observe and record what happens when the ladybugs reach the smooth surface.

Questions to Think About

1. Which surface do ladybugs prefer?
2. How would you explain the preference?
3. Does this behavior help the ladybugs to survive?
4. How can you find out which receptors the ladybugs use?

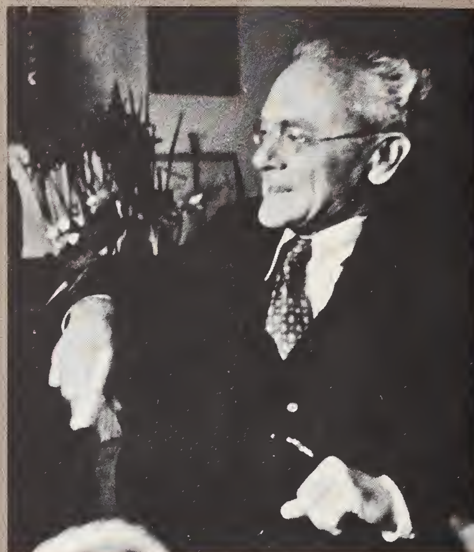
Perhaps the most important feature of animals is the many ways they are able to change as their environment changes. In studying each animal as a whole, we find that these changes are rarely simple reactions.

All the adjustments we have talked about are not planned by the animal.

PATHFINDERS IN SCIENCE

Karl von Frisch

(1886–) Austria



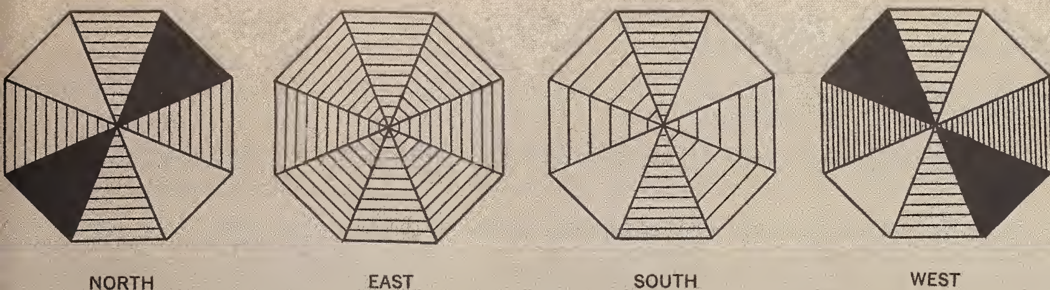
One day in 1923, Karl von Frisch, a zoologist at the University of Munich, Germany, laid a sheet of white paper on a table he had set up in a field. He placed some honey on the sheet of paper and waited for a bee to come. He was studying the habits of bees, and this was his way of attracting them.

Sometimes he waited several days for a bee to appear. But he noticed that soon after the first bee had discovered the honey and flown away again, other bees came—sometimes hundreds at a time.

This puzzled von Frisch. He wondered whether the first bee had led the other bees to the honey. If so, how did the first bee tell the others what it had found? To find out, he decided to conduct a series of experiments. He built a hive with glass walls and attracted a swarm of bees to it. Then he marked several of the bees with spots of color so that he could easily follow their furious movements.

In this way, von Frisch discovered that the bees did a dance in order to tell each other where they had found nectar. If the first bee discovered a rich supply of nectar close to the hive, it would return to the hive and begin to dance in circles. If the nectar was far from the hive, the

The queen bee does not send a message out saying, "Flap your wings: it's getting cold." Somewhere in an animal's nervous system, information from sensory receptors is pieced together, and the proper adjustment is made. In the rest of this unit you will find out what happens in the nervous system.



Bees use the pattern of polarized light from the sky to find the sun's position. Von Frisch found that if he artificially disturbed the pattern, the bees' dances changed. Above are four patterns made by von Frisch. If he used a pattern he could not identify in the sky, the bees danced with no particular direction. Find out more about these patterns.

first bee would do another kind of dance. It would wiggle its body from side to side while facing in one direction. The wiggles told the other bees how far away the food was and the direction in which the first bee faced told them in what direction to fly.

The other bees would gather around the dancing bee and soon they would fly from the hive to search for the nectar the first bee had found.

If the bees swarmed from their old hive, scouts would search ahead for suitable new hives. The scouts would report back by dancing in special ways. The dances told the other bees what the scouts had found. Soon the entire swarm would set off for their new hive.

During his experiments, Karl von Frisch did nothing more exciting than watch his bees closely and note carefully how they behaved. He made records of all that he saw. His experiments were as exciting to him and to other scientists as a football or baseball game is to others.

Von Frisch's experiments with bees have led to an increase in our understanding of communication among insects.

Using What You Have Learned

1. Do you now have a list of key ideas about animal senses? Check your list against the following list, and find examples of each of these key ideas:

a. The sensory equipment of an animal helps it to survive.

b. Complicated sensory equipment took millions of years to develop.

c. The structure of sensory receptors is related to what they do.

d. There is both variety and similarity in the ways in which animals take in information from their environments.

2. Can a goldfish hear? Write a plan for an experiment to find out. How can you be sure that it is what the fish hears that changes its behavior and not what it sees, feels, or smells?

3. Insects have mosaic eyes made up of separate facets. Not all light waves pass through. A polaroid filter will also keep out some light waves. A polaroid filter has tiny crystals that let only certain light waves through.

Use polaroid sunglasses or a polaroid filter to examine the shiny side of aluminum foil in bright sunlight. Turn the polaroid filter around slowly while you examine the foil. What change do you notice in brightness?

Look at the sky on a cloudy day and on a sunny day. Turn the polaroid filter as you look. How does the polaroid filter change the light? Write about the changes that you have seen.

4. One good way to observe insect behavior is to make a simple cage in which insects may be kept. You will need a lamp chimney screened at the top and pressed into the soil of a flowerpot containing a growing plant. You will also need a dish in which to keep the flowerpot. Some string or a rubber band will hold the screening tightly to the lamp chimney. What will serve as insect food?

Explaining Behavior

You have learned how an animal senses what is happening around it. You have seen that sensory receptors can be stimulated in various ways. However, this does not *explain* an animal's behavior. It only tells us how an animal gets information.

To explain behavior, we must study the nervous system. The nervous system controls behavior. When the school bell rings, your sensory cells for sound are stimulated. The stimulation is passed along sensory nerves to the brain. But your brain does not send out a message to the motor nerves to get up and go. The meaning of the bell is checked against other meanings stored in the cells of your brain. You search for more information. You automatically glance up at the clock to see if it is the right time for dismissal. You look at the teacher to see if she has heard. You look at your work to see if it is ready to hand in. All of these bits and pieces of information are fed into the brain by the sensory nerves before a message goes out to your motor nerves.

Can you explain the behavior of children playing in the schoolyard when the school bell rings for the start of classes?

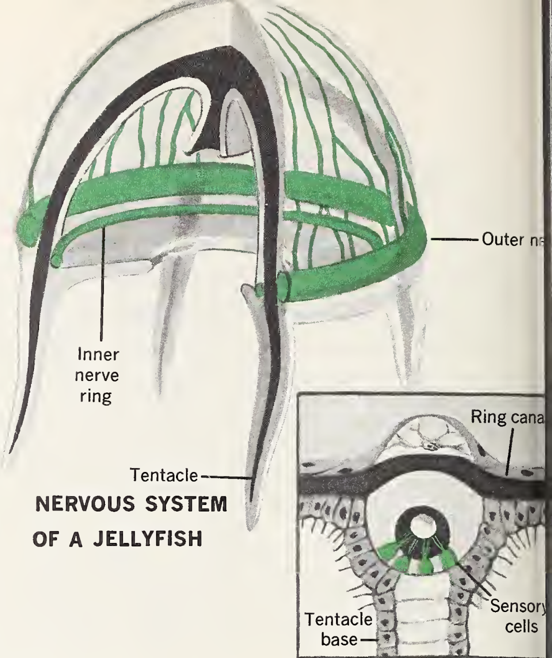
How the Nervous System Developed

Not all animals have a nervous system. You know that in the course of the earth's history, living things have changed. The first animals did not have nervous systems. They were simple animals with one cell to carry on all the work an animal needs to do to stay alive.

Very slowly, changes appeared. Animals became more complex. Many-celled animals came into existence, with many parts to their bodies. For these animals to survive, the many parts of the body had to work together. The nervous system has the job of **coordinating** the parts of the body.

Over a billion years ago, animals like the jellyfish appeared. This animal has a very simple kind of nervous system. The jellyfish has a few sensory receptors and a nerve net through which messages go back and forth. Look at the picture to see the nerve net of the jellyfish.

Gradually nervous systems became more complicated. In animals like the flatworm, nerve cells are clustered in a tiny mass between the eyes. This is a kind of "early" brain. Nerves branch out in all directions from this brain, bringing in information from the senses and carrying messages out. In this way, the various parts of the animal work together.



NERVOUS SYSTEM OF A JELLYFISH

NERVOUS SYSTEM OF A PLANARIAN

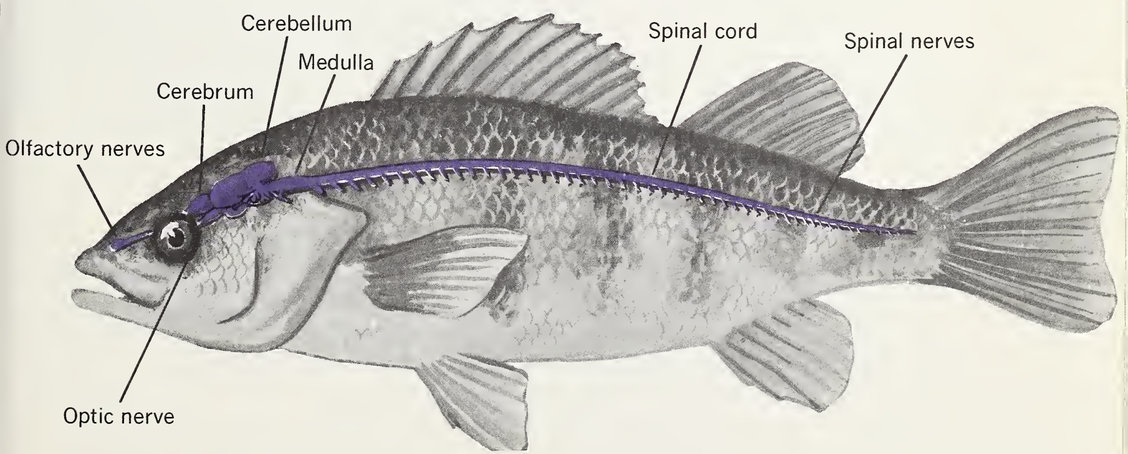
The Nervous System and Behavior

The fish has a **central nervous system** like the one in the picture. A central nervous system consists of a brain and a spinal cord. You remember that ethologists have found out many things about the behavior of the stickleback fish. What happens in the nervous system that causes its behavior? Let us look at the food-getting behavior. By experimenting, scientists have discovered that the stickleback (1) searches for food with more or less energy depending on how empty its stomach is, the kind of food nearby, and the temperature of the water; (2) eats fast at first and then slows down; (3) eats enough to keep its stomach full up to a certain limit; (4) may turn to food when there is a conflict between two other kinds of behavior—perhaps fighting and escape.

Before the stickleback searches for food, the fish must have information about how cold the water is, what kind of food is nearby, and how full its stomach is. Only then can the brain send out the proper message to other parts of the body. There must be a central system where information is brought in about what is going on around and inside the stickleback.

Scientists think that there are centers in the nervous system to handle various jobs. One such center might control appetite. In their natural surroundings, fish do not die from overeating. Some food goes by, and the

NERVOUS SYSTEM OF A FISH



message is taken in by the fish. The message goes to a center where appetite is controlled, and the message is checked against information there. If the information is that the stomach is full enough, this information is fed back into the food-seeking center, and the fish ignores the food.

But ethologists know that the temperature of the water affects how much the stickleback eats. The fish eats less when the temperature is low. (In general, the work of cells is speeded up by heat and slowed down by cold.) The appetite-control center must also get the information about how cold the water is. The center must balance information about both stomach fullness and temperature. Only then can it send out the correct message—to eat or not to eat.

Why, then, may the stickleback begin eating during a fight? Scientists think that the center that controls food-getting must be very close to the center that controls fighting. The fish uses its mouth for both fighting and eating. Therefore, information that something is in the mouth is carried to *either* the food-seeking center *or* the fighting center. If that "something" in the mouth is an enemy, the message ought to go to the fighting center, so the fish will continue to fight. But if the centers are very close together, the message may end up in the food-seeking center. Then the stickleback, in the middle of the fight, begins to search for food!

Centers for temperature and appetite control in mammals are located in a part of the brain called the **hypothalamus** (hy-poh-THAL-uh-muss). Nerves carry messages from the senses to the hypothalamus. Cells in the hypothalamus are stimulated and release chemicals. The chemicals act as messengers to put other systems into action.

Scientists go underwater to study the behavior of certain fishes.

Today some of the most exciting work in science is being done on these chemical messengers. When more is known, perhaps behavior can be explained in terms of what happens within the cell.

Using What You Have Learned

Use what you now know about how animals behave to do the following experiments.

EXPERIMENT

Does Temperature Affect the Appetite of a Goldfish?

What You Will Need

a goldfish	fish food	ice cubes
bowl	water	

How You Can Find Out

1. Fill the bowl three-quarters full of water, and let it stand overnight. This will remove the chlorine.
2. Measure the temperature of the water. Record the date and the temperature.
3. Place the goldfish in the bowl.
4. The directions on the package of fish food will tell you how much to use. Feed less than the amount suggested so that the fish will eat it all. Measure the same amount of food each day for one school week. Skim off any uneaten food after an hour, dry it, and measure it. Feed at the same time each day.
5. Keep a record of the water's temperature and how much food the fish eats.
6. The next school week, lower the temperature of the water one hour before feeding time. Take out some water and add ice cubes until the water temperature is 20° F. lower than it was before. Repeat #4 above.

Questions to Think About

1. Does the appetite of the fish change when the water is cooler?
2. Are living things more active when it is cold or when it is warm?

Does Temperature Affect How Fast Animals Develop?

What You Will Need

containers of pond water
elodea
electric light
thermometer
frog or toad eggs
boxes

How You Can Find Out

1. Look for eggs in ponds or swamps in late winter or early spring. Some frogs lay eggs that float on water in a mass of clear jelly. Bring in one of the egg masses in a bucket of pond water.
2. Divide the mass into three batches. Put the batches in containers of pond water—having elodea plants—in three places where the temperatures are different. One batch might be inside a box. The electric light will keep the temperature of the box higher than room temperature. Record the temperature of the box every day at the same time.
3. Make a second box, but put no light in it. Put a second container of eggs inside. Chill it twice a day by adding ice cubes of frozen pond water, first removing some of the warmed water.
4. Keep the third set of eggs at room temperature. Record the temperature.
5. Examine each egg mass every day with a magnifying glass. Write down a description of what you see in each mass.
6. On which day do you first see tadpoles appear as the eggs hatch in each box?

Questions to Think About

1. How does temperature affect the speed of hatching?
2. Do you think seasonal changes affect the development of animals? How can you find out?

Is Animal Behavior Inherited or Learned?

You have seen that there is a great variety of animal behaviors. You have seen that these behaviors are made possible by the structure of the animal—its sensory equipment and its nervous system. But how can we explain the fact that a robin builds a nest that is different from a cardinal's nest? Do robins watch other robins and learn from them? Are they born knowing how to build a nest in a certain way? Did the stickleback learn, or was it born with, its way of defending itself?

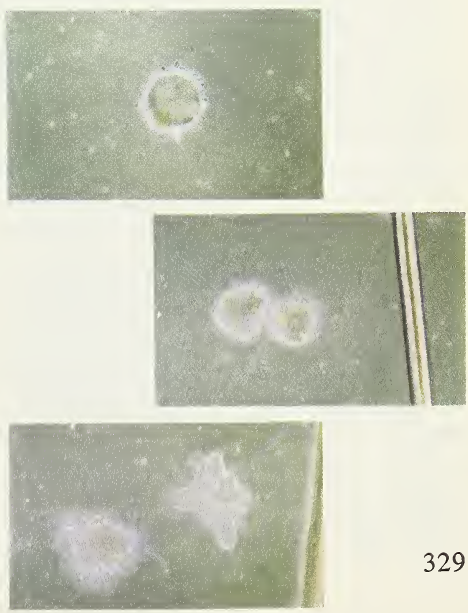
Early Ancestors of Animals

To find part of the answer to our question, we must go back into the history of animal life on earth. If we could go back a few billion years, scientists think that we would find only one-celled animals. These animals lived in the sea. After millions of years, more complicated animals appeared. They were offspring of the single-celled animals.

A one-celled animal reproduces by dividing in two. But the split is not necessarily an exact one, and the two new animals are usually not identical. At some point in the earth's history, an offspring appeared that was very different; it had more than one cell. Perhaps this difference was the result of changes in the chemicals in the sea. No one knows for sure. When this animal reproduced, it passed on the differences to its offspring, who in turn had offspring with more than one cell. An entirely new group of animals gradually came into being.

You know that offspring from the same set of parents are not identical, unless they are identical twins. You are different from your brothers and

Two animals from one. The ameba reproduces by splitting in two.



sisters. Puppies in the same litter are different. So are kittens. Some of the differences are passed on to offspring. The offspring then have these new characteristics.

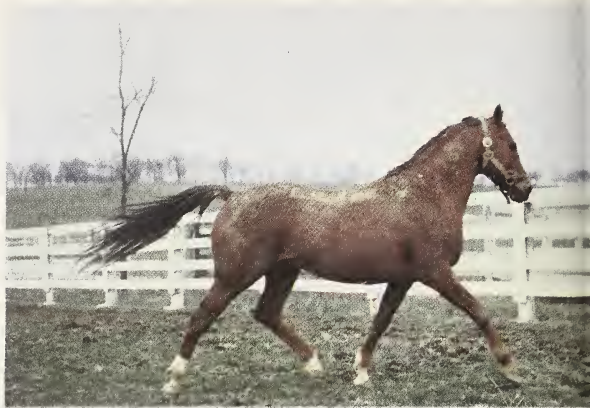
The differences may be very slight from one generation to the next. If one puppy has thicker fur than its parents, then perhaps some of its puppies will also have thicker fur. Changes go on generation after generation. They have been going on for millions of years. They explain why we have a tremendous variety of living things on earth today.

The story of how dogs and cats developed shows us how the process works. If we could go back in history about 50 million years, we would find that there were no dogs and cats. There *was* a family of animals called **Miacidae** (my-uh-SIH-dee), which were about the size of house cats. The miacids were hunters and had claws and teeth suited to a diet of fresh meat. Like those of all animals, the offspring of a pair of miacid parents differed slightly. One of the offspring was larger and stronger than its miacid parents. It also had longer legs. The longer legs enabled the animal to run faster and hunt better. The larger size and greater strength made it easier for the animal to hunt larger prey. This animal, because it was such a good hunter, was able to live a long time and have many offspring. Its offspring had larger and stronger bodies and longer legs than its miacid ancestors. The offspring stood a better chance of surviving and of having babies than did the ancestor miacids. Today the descendants of these animals form the family of **Canidae** (KAN-uh-dee). Wolves, foxes, coyotes, and dogs are some of the animals in the canidae family.

At some point in history, one of the miacids gave birth to an offspring that was different in another way. This offspring had very sharp claws. Its teeth were different from its parents'. It could hunt and eat prey that an ordinary miacid could not manage. This animal could climb trees to lie in wait for prey, pounce on it, and hold it tightly in its sharp claws. Offspring of this animal formed the family called **Felidae** (FEE-luh-dee). Lions, leopards, wildcats, and house cats are some of the animals in the Felidae family.

Changes are still going on. They occur so slowly that we do not notice most of them. Sometimes we read about one in the newspaper. For example, one news report told about a new variety of insect that has appeared. The new kind looks like the old, but it is resistant to the sprays that man has been using against the old. That is, the spray is not deadly to the new variety.

These pictures show members of the Canidae family and the Felidae family. How are they alike? How do they differ?



Here you see three examples of how animals have adapted. Can you tell what adaptations these animals have made to their environments? How do these adaptations enable them to survive?

Adaptations of Animals

A change in the structure of an animal that makes it easier for the animal to survive is called an *adaptation.* Adaptation is one of the key ideas in the science of biology. The claws of the cat are adapted for climbing, and the legs of the dog for running. The long neck of the giraffe is adapted for eating leaves from the tops of trees. Would there be many other animals feasting on these leaves? How would the ability to reach so high for food help the giraffe to survive?

When we examine the many, many forms of animal life, we find examples of adaptation in each form. On a single tree, for example, there may be insects that are adapted for living only on the leaves. Others make their way into the bark or into the trunk of the tree. Some insects are adapted for living near the top of the tree, where there is more light. Others may live on the roots. How do these adaptations help them to survive? What would happen if all insects ate from the same part of the tree?

Changes in Structure and Behavior

With changes in structure, different behaviors are possible for an animal. With sharp claws a cat can climb a tree, while a dog cannot climb it. But dogs and cats are different in many other ways, as you know. Dogs tend to be friendly, sociable animals that are easily trained. They can learn to get along in many kinds of homes. Cats, on the other hand, are very "independent." They can be trained, but training is difficult. Just try to teach a cat to stay off the kitchen table!

Why the difference? The difference can be explained in part by the history of the animals. Members of the dog family—wolves, foxes, and others—are adapted to hunting in packs. They are good runners, and by hunting together they can chase a victim in circles, tiring it and making it easier to catch. Cats are built so that they hunt better alone. They cannot run fast for long periods of time. By lying in ambush, a cat can pounce on a victim and hold it with its sharp claws. This is a type of hunting that is best done by a lone animal. Most members of the cat family are adapted to this kind of hunting. House pets, of course, no longer need many of the skills their ancestors needed.

The history of how animals have adapted helps to explain differences in behavior. Dogs have a long history of being *social,* a behavior that goes along with their structure. Cats have an equally long history of *living by themselves.* Dogs and cats that behaved in these ways survived; others did not.

Are They Born That Way?

Are dogs and cats born with their special ways of behaving, or do they learn these ways through experience? This is a question that has interested scientists for many years. There has been a great deal of research on animal behaviors to find the answer.

One kind of animal behavior that has been studied is *following* behavior.

Some animals, as you know, follow after the mother animal. Ducklings and lambs are two kinds of animal that do this. Can you name others?

Scientists used to think that animals were born with behaviors such as following behavior. They used to think these behaviors would appear no matter what happened to an animal after birth. But experiments have shown that this is not so.

In one experiment ducklings, shortly after hatching, were shown a wooden duck. The wooden duck was wired so that it could move. One by one the little ducklings fell in line behind it. A few days later they were put out in a pond. Their real mother was there, but they continued to follow the wooden animal.

Scientists have learned from experimenting and observing that animals that follow are not born with a follow-after-mother behavior. How, then, can it be

explained? Scientists continue to experiment to find answers. They also experiment with other behaviors, such as the pecking behavior of chicks. They have found that an infant animal must sense the proper *sign* at the proper *time*. It must see something or smell something or hear something or feel something—but it must be the right something at the right time.

In the case of the ducklings, the proper sign is any moving object; the duckling *must* see some object move. The message that something is moving is carried to the brain. In the brain, certain cells are stimulated. When the cells are stimulated, chemical messengers are released to other parts of the nervous system. Then the ducklings begin to follow.

The cells are sensitive to this special stimulation for just a short time. The 13-to-16-hour-old ducklings are at the best age to start to follow. If they are more than a day old before seeing a moving object, the ducklings are not likely to follow.

Remember that not all animals follow a moving object. A puppy or kitten does not follow its mother wherever she goes. An animal must be born with nerve cells that make this kind of behavior possible. Chemicals in the cells must be put together in such a way as to be stimulated by a certain kind of sign. Ducklings, goslings, and lambs are born with cells that can be stimulated when they see a moving object. Other behaviors require other kinds of signs for their release.

Releasers

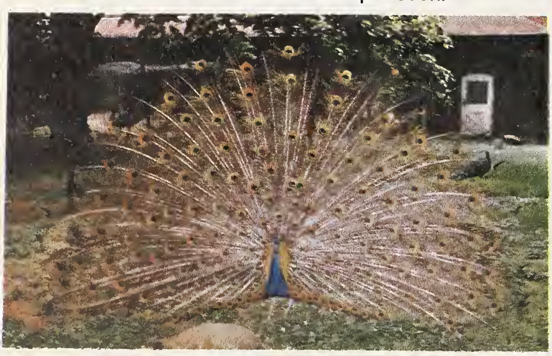
Whatever stimulates a kind of behavior is called a *releaser*. Ethologists are very interested in finding the releasers for particular behaviors. They look for something in one animal that releases a particular behavior in another of the same species. The releaser is like a key that unlocks the door to particular behaviors. It may be color, special markings, movement, odor, or sound.

Perhaps you have seen a male bird in the spring courting a female. Some birds put on quite a show, fluffing up their feathers and strutting about. What is there about the female that releases this courting behavior? The male does not strut about before another male. How does he know the difference between a male and a female?

An experiment was done with flickers. The male and female flickers look alike, except for the color of the moustache under the bill. The male's moustache is darker than the female's. Ethologists captured the female of a pair and dyed her moustache to match the male's. When she tried to go back to the nest, the male chased her away in fury. The dark-colored moustache close to the nest released fighting behavior, whereas the lighter-colored one had earlier released courting behavior.

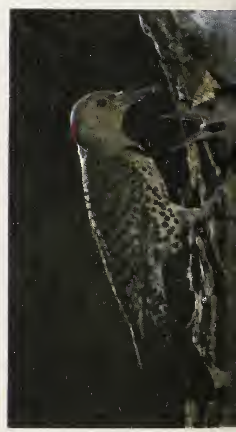
Remember how the male stickleback defended his territory from all other males? Males have a long, red belly. Females have a gray-colored belly, which is rounder in shape when they carry eggs. Ethologists made a dummy model of clay, rounded in shape but with a red belly. The stickleback attacked it. But when the red color was removed, he made gestures to invite the dummy into his nest!

The male peacock displays his brightly colored feathers to attract the female peacock.



Male flicker

Female flicker



Scientists are interested in the way in which behavior begins. They see behavior as resulting from what goes on between the animal and its environment. They think that what an animal inherits is like a picture that is not finished. The details are filled in as the animal responds to things in its environment. Scientists find patterns of behavior and then try to find out why and how and when these patterns appear. In their studies, they continue to search for the key ideas to help them understand animal behavior.

Using What You Have Learned

1. List examples of adaptation to environmental change, such as the ways bees are adapted to cold. How many other examples can you find?

2. Scientists have studied the ancestors of the modern horse. They have traced changes from very early ancestors. Prepare a special report on these ancestors, answering the following questions:

a. How did the earliest-known ancestor differ from the modern horse?
b. How do we know that such an animal existed?
c. What changes were there in feet, teeth, and size as offspring came along?
d. Why are there no longer animals like the ancestors of the horse?

3. Find out more about how the behavior of dogs differs according to breed. People who raise dogs for sale usually specialize in one breed only.

Invite two people who raise dogs of different breeds to class. Ask each to tell about the behaviors of the breed he raises. Plan the questions you will ask under such headings as "playfulness," "getting along with people," "fighting," and "amount of activity."

WHAT YOU KNOW ABOUT

How Animals Behave

What You Have Learned

Behavior means all the activities of an animal except those that are automatic. Scientists who study animal behavior are called **ethologists.** An ethologist searches for key ideas that explain behavior.

Animals have senses that tell them what is happening in the world about them. An animal's **sensory** equipment includes sensory receptors. These receptors are made up of cells that are sensitive to different kinds of information. The different kinds of sensory receptors include **chemoreceptors, photoreceptors, thermoreceptors,** and **mechanical receptors.**

Complicated animals have a **central nervous system** that consists of a spinal cord and a brain. The central nervous system **coordinates** the different parts of the body. Within the part of a mammal's brain called the **hypothalamus** there are control centers for appetite and temperature.

Animals have evolved during the course of millions of years. The adaptations of animals to their environments have made it possible for the animals to survive.

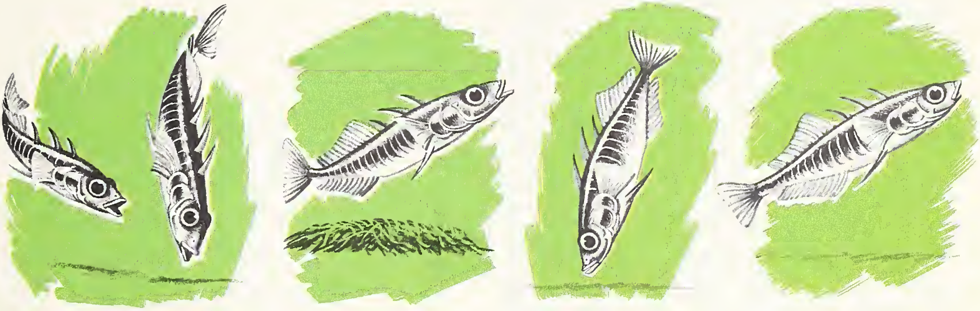
Checklist of Science Words

Here are some science words you read about in this unit. Can you tell what you have learned about each one?

acclimatize	ethologists	mosaic
chemoreceptors	facets	photoreceptors
coordination	hypothalamus	sensory

Name the Key Idea

Look at the pictures below. For each picture tell what key idea about the stickleback's behavior can be applied to the behavior of other animals.



Matching Test

Write the numbers 1 to 9 on your paper. Next to each number write the letter of the word or words described.

1. Receptors stimulated by tastes and smells.
2. Receptors stimulated by light.
3. Receptors stimulated by changes in temperature.
4. Adjusted to a climate.
5. Receptors stimulated by touch, pressure, and sound.
6. The brain and the spinal cord.
7. Location of centers for temperature and appetite control in the mammalian brain.
8. A change in the structure of an animal that makes it easier for the animal to survive.
9. What sets in motion a response characteristic of that species.

A. releaser
B. hypothalamus
C. mechanical receptors
D. acclimatized
E. thermoreceptors
F. adaptation
G. chemoreceptors
H. photoreceptors
I. central nervous system

YOU CAN LEARN MORE ABOUT

How Animals Behave

You Can Observe Color Changes in a Chameleon

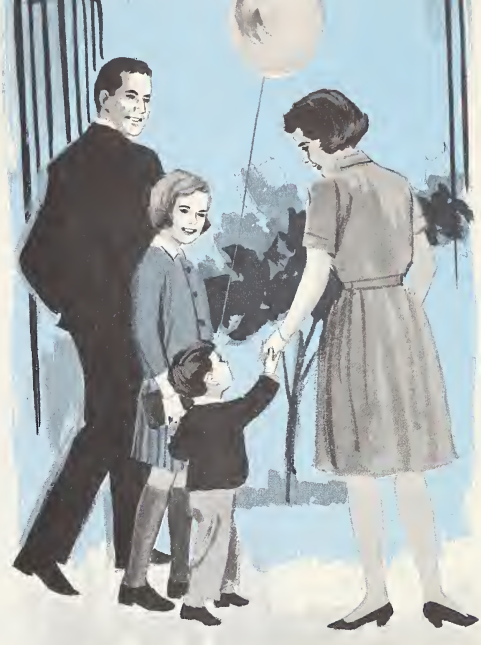
Make a chameleon home as shown in the picture. Next, buy a green chameleon at a pet store or a science-supply house. Chameleons need live food such as mealworms, flies, and moths. Hang a bit of meat or fruit on a string to attract flies. Every other day sprinkle water on the plants in the chameleon home. The chameleons will drink the drops on the leaves. Place the cage where it will get a few hours of sunlight each day. Keep the temperature at about 80° F. In winter, place a 25-watt bulb in one corner of the cage. Make sure there are always some shady places in the cage.

Place the chameleon on green and brown cloths. What happens? Does the chameleon change color in response to temperature and light? Try taking the chameleon outdoors when the temperature is about 50° F. What happens? With the temperature indoors at 70° F., put the chameleon in a bright place. What happens? Place it in a dark place. What happens? Raise the temperature of the cage to 105° F., taking care that the environment remains humid. What happens?

Study the animal's appearance. How does its long tail help it to keep its balance? How do its long toes help it to run on branches? How does it eat? How does it drink? How does it compare with other reptiles? How is it adapted to living in trees?

You Can Visit

A good place to observe how animals behave is a zoo. Many zoos have exhibits in which animals roam woodlands and plains in settings very much like the environments in which the animals naturally are found. Zoos also try to provide the animals with diets and temperature conditions similar to those found in nature. To find the zoo nearest to you, write to your local chamber of commerce.



You Can Read

1. *Winter-Sleeping Wildlife,* by Will Barker. The life cycles of animals whose activities slow down at certain times of the year.
2. *The Strange World of Animal Senses,* by Margaret Cosgrove. Tells how various senses are combined in an animal to enable it to survive in its environment.
3. *Animal Habits,* by George F. Mason. Tells about instincts, communication, and other behaviors of animals.
4. *Animal Behavior,* from the Life Nature Library. A well-illustrated book on animal behavior and the kinds of research that have been done on animals to study behavior.
5. *How Animals Live Together,* by Millicent E. Selsam. Tells about animal relationships.

9

Science–Today and Tomorrow

Science in Today's World

Bionics—The Science That Copies Nature

Biopower—Energy from Living Organisms

Cryogenics—The Supercold World

Lasers—Light Brighter Than the Sun

Ultrasonics—The Sound You Cannot Hear

You and Science for Tomorrow's World

Galileo, Copernicus, and others started a revolution in science that continues today with an almost unbelievable flow of new knowledge. Scientific and technical information pours from universities and research laboratories. The scientific revolution is shaping your world of today and tomorrow.

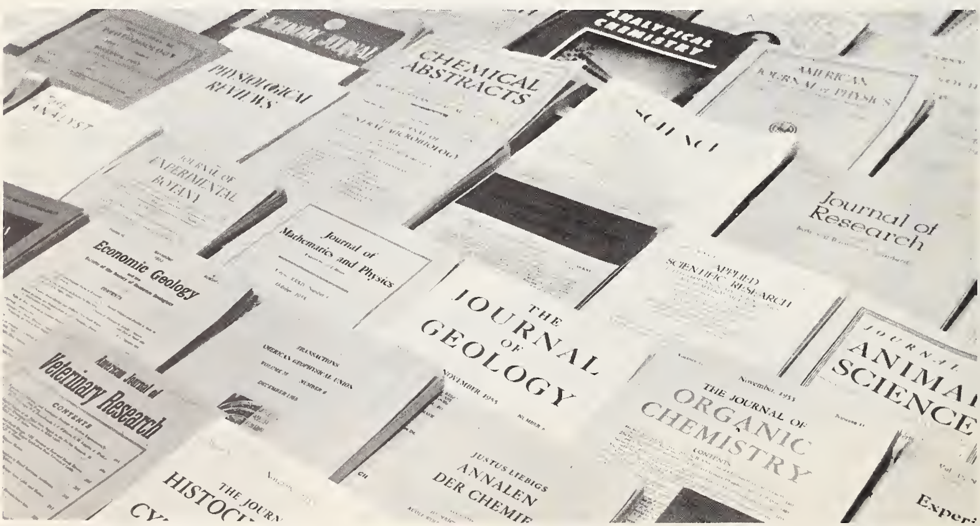
Science in Today's World

Scientific knowledge has been doubling every ten years since about the middle of the eighteenth century. You have available 8 times as much knowledge as your father had, 64 times as much as your grandfather had, and over 1,000 times as much as your great-grandfather had.

Every year, over a million and a quarter research reports are published in the biological and physical sciences. Even more amazing is the increase in the number of scientists and in the number of scientific careers. Ninety per cent of the scientists who have ever lived are alive today!

Suppose we drew a graph of scientific advances made from the dawn of civilization to the year 1945. If we plotted the rising curve so that it reached a height of 4 inches for 1945, we would need a chart as tall as a

Here you see only an armful of the more than one million research reports published each year. How many areas of science can you identify in the reports shown?



How do these two results of modern science affect the world in which you live?

thirteen-story building to plot the progress from 1945 to 1960! From 1960 to today and into tomorrow, the curve moves ever upward. How high will it reach? How great is man's desire for knowledge?

Science in Our Lives

Today, science is a part of almost everything we do and see. Some of the results of modern science are easy to see—rockets, nuclear-powered ships, jet airliners. Some other results of modern science are not so easily seen—the clothes we wear, the amount and kinds of food we eat, the way we live together in cities, the healthier, longer lives we lead, and many other things.

Modern science has changed the way man thinks about himself and the world in which he lives. Once man lived in constant fear of hunger, pain, and death. Man's food supply depended on acts of nature, which he believed were controlled by the gods. Great plagues wiped out families and whole villages without warning. When lightning and raging winds struck, man thought he was being punished for his sins.

Science has reduced man's ignorance and helplessness. Even when man has not yet been able to control the forces of nature—such as hurricanes and tornadoes, or unconquered diseases such

as cancer and the common cold—man now feels that he knows a great deal about them and that soon he may be able to control these too.

The discovery of the microscope led men to find the causes and cures of many diseases. Discoveries about electricity led to the invention of the radio, the telegraph, the telephone, television, power generators, and other devices. Once the doors to scientific knowledge were opened there was a flood of discoveries and inventions.

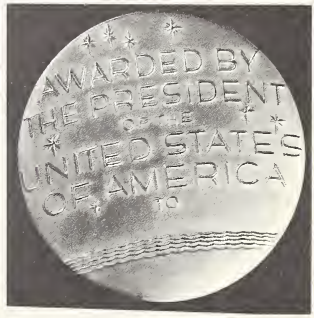
In 1866, someone suggested that the United States Patent Office, which registers inventions, might soon shut down, since everything would surely have been thought of. But instead, more and more ideas—new ideas—came. Today, ideas come at an even greater rate as new discoveries lead to more knowledge of our world and new knowledge leads to new discoveries.

Today our country and other advanced countries support scientific endeavors and reward achievement. In 1964, Nobel Prizes in physics, chemistry, and medicine—the highest awards in science—were given to two Americans, two Russians, an Englishman, and a German. In 1965 the United States Congress awarded 11 scientists the National Medal of Science. All these men and women are pathfinders in the science of today.

In this unit you will read about five of the many new branches of research in science and about some of the scientists who are pathfinders in the science for tomorrow's world.

The Nobel Prize, shown on the right, is awarded to the world's outstanding scientists.

President Lyndon B. Johnson presents the 1965 United States National Medal of Science. As a project, find out about the contributions made by the winners.



Using What You Have Learned

1. In 1638, Galileo published a book called *The Two New Sciences*. In so doing, it is said that he changed man's idea of nature and thus triggered the scientific revolution that has shaped today's world. Can you explain this statement?

2. Who was Alfred Nobel? What is the purpose of the Nobel Prizes?

3. Make a chart to show how various discoveries such as the microscope, the telescope, and the germ theory of disease sparked new knowledge and understanding of man and the world in which he lives.

4. How is scientific achievement rewarded in countries such as Great Britain, France, and Russia? Why is it important to reward such achievement? Find out how citizens can support scientific work.

Bionics—The Science That Copies Nature

A bat can fly through a dark room strung with dozens of piano wires and not touch even one of them. A snake can react to changes in temperature as small as 1/1000 of a degree. By vibrating its wings, a mosquito can set up a hum that will signal another mosquito 150 feet away even when thunder roars or fire engines' sirens scream. How can animals do these things?

Scientists have long been interested in these animals. They have tried to find out about the special equipment that enables a bat to sense objects near it. They seek the sense organs that enable a snake to detect very small changes in temperature. And they want to know how a mosquito is able to signal through loud noises.

Scientists believe that finding the answers to these questions may lead to many important inventions. In 1960, a new branch of science was born. Lt. Colonel Jack E. Steele, a flight surgeon in the United States Air Force, gave the name *bionics* to this new branch of science. **Bionics**, like biology, is the study of life. But bionics scientists, or bionicists, study life for a special reason. They study living systems to find out what makes them work. With this knowledge, engineers may be able to copy these living systems.

Lt. Colonel Steele is a physician who studies living systems to find out what makes them work and then uses the knowledge he gains to try to improve man-made systems.

Bionics uses a *team approach* to research—biologists work with others.

Making a Copy of Nature

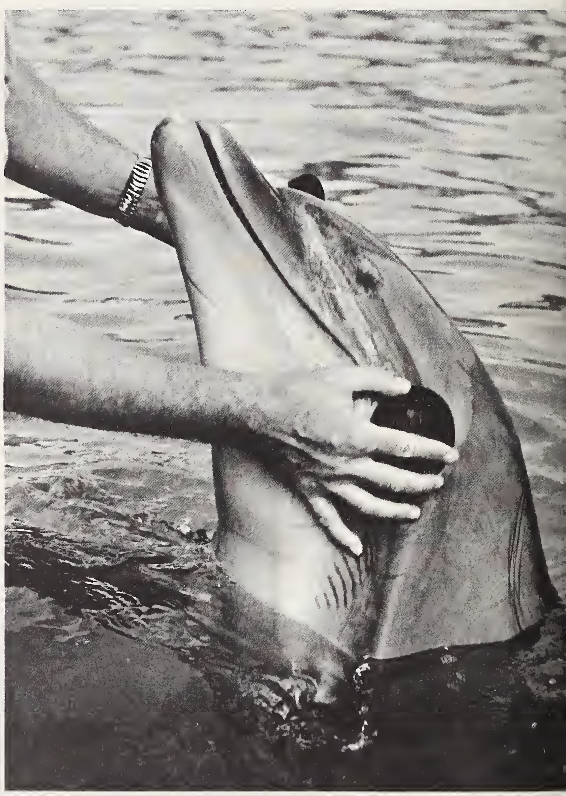
Let us see how a copy of nature might be made. There are two tasks involved. The first is to find out how an animal's body or part of a body works. Suppose researchers want to find out how a frog's eye works. First they track down the connections from

A frog's eyes screen out every movement that is not important to its own life. Scientists study the frog's eye to learn how to develop, for example,an air-defense system that is better than radar.

eye cells to brain cells and try to understand what goes on within them. The second task is for engineers, mathematicians, and others to try to duplicate what has been learned from the model made of the living frog's eye. Bionicists are working in a very new science, but already they have had some successes. The study of birds has given bionicists answers to important questions about the shape and curve of bird wings, and the bionicists have been able to apply this knowledge to improving the design of aircraft wings.

How might the study of birds enable scientists and engineers to improve the design and manufacture of airplanes?

Scientists studying communications have been studying the dolphin. They believe that the dolphin uses sound navigation. Tape recordings have been made of dolphin whistles, clicks, barks, and jaw-clacking noises. The picture below shows rubber suction-cup discs placed over each eye of a dolphin. The dolphin cannot see this way and must rely totally on its senses of hearing and sonar-sounding to find its way.



Fish gills are being studied so that better underwater breathing equipment for humans can be designed. Much research is being done to find out how the dolphin—a mammal—swims as fast as it does. Scientists believe that the structure of the dolphin's skin may help his swimming. Now they are experimenting with a rubberlike coating for boats the texture of which is very much like that of the skin of the dolphin. Perhaps this coating will lessen the drag on boats moving through the water.

Scientists doing research in communications are also studying the dolphin. Its ultrasonic whistling has been found to be a form of communication among dolphins. Perhaps ways will be found to adapt this technique so that it can be used for underwater signaling among humans, or even for communication among humans and dolphins and other living things.

A beetle's eye has already been used as a model for a device to make better ground-speed indicators for aircraft. Ground speed is the velocity of an airplane, for example, with relation to the surface of the earth. The beetle's two-part eye lets it judge its own speed. One part of its eye sees an object before the other part sees it. The time interval tells the beetle how fast it is going.

In copying the beetle's "indicator," Air Force scientists use two electric eyes—one in the nose of a plane, the other in the tail. In place of the beetle's brain, they use a small electronic computer.

A cockroach can detect movements of only millionths of an inch much better than any present man-made device. How does it do this? Finding out may help scientists make their present instruments more delicate and precise.

Scientists have made mechanical "noses," based on what they have learned about the sense organs of animals, that can "smell" very faint odors. Such devices, if they can be made as efficient as animals' noses, may help warn of dangerous gases and spoiled foods.

Joining Living and Artificial Systems

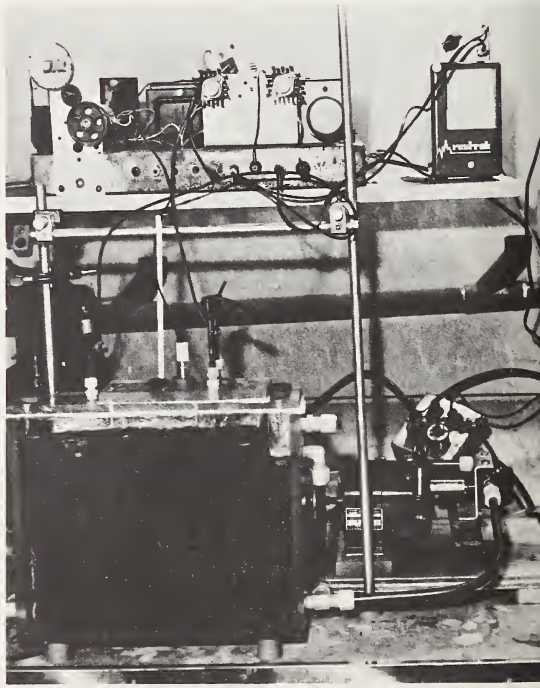
Scientists are also attempting to join together living and artificial systems. An example of this is a system in which an astronaut is attached to a type of booster that operates his arms for him when he is under such great forces that he is not strong enough to move his arms. The booster uses signals from the astronaut's muscles to control motors for moving his arms. There are uses for such a system in space and in very cold or very hot environments,

where people are unable to move their muscles normally. Such a system may also enable people who have lost the use of their arms and legs to move about. Artificial limbs might also be more useful with boosters.

Bionics, the science that copies living systems, is providing a two-way exchange of valuable results. The engineer is learning to make better artificial systems from his study of nature, and the biologist is learning more about his subject, living systems, from the work of the engineer. Bionics will lead to a better understanding of the world in which we live.

Biopower—Energy from Living Organisms

Imagine an electric battery made up of bacteria! Imagine a radio transmitter powered by this battery. Does this sound like science fiction? Indeed it is not! In 1962 a team of scientists generated practical amounts of electricity from living organisms and put it to use. The radio transmitter they demonstrated had a range of only 15 miles, but scientists were as excited by it as if its range had been millions of miles.

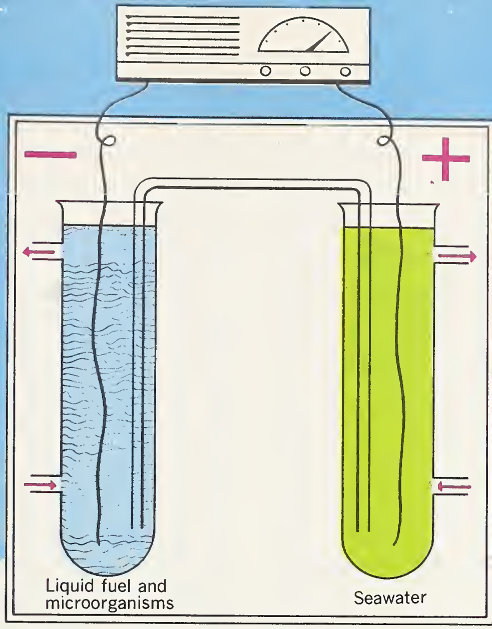


The biocell at the bottom of the picture was used to power the radio transmitter above it.

The Biocell

This new power supply is called a **biocell.** Using a liquid fuel and microorganisms such as bacteria, a biocell changes chemical energy directly into electrical energy.

All living things are really biocells. The difference between a living thing and a man-made biocell is that the fuel



This diagram shows how the biocell works to produce energy to power a radio transmitter. Can you trace the flow of electrons that produces the electrical circuit?

in a living thing gives off energy in the form of heat instead of in the form of electricity. The scientist's task is to cause the "burning" of fuel by an organism and then change the heat given off into a flow of electrons—that is, current electricity.

This process is very much the same as changing chemical energy to electrical energy in the simple battery or voltaic cell. Two different elements such as zinc and carbon are placed in a water-and-acid solution. The zinc is called the negative pole and the carbon is the positive pole. The acid attacks the zinc as if it were burning it. As electrons flow from the zinc of the negative pole to the carbon of the positive pole, energy is given off in the form of electricity.

The biocell is more efficient than the voltaic cell. In the biocell described on page 352 that powered the radio transmitter, Dr. Frederick Sisler, a scientist, used bacteria for the negative pole of the cell. The bacteria were in a test tube, as were sea water and other material for fuel. The positive pole contained sea water and oxygen. The electrons moved from the fuel (negative pole) through an electrical circuit to do the work.

Advantages in Using Biocells

What advantage does the biocell have over our present ways of producing electricity? The biocell can draw energy *directly* from living things, which our present electrical generators cannot do. When you flip the switch on a lamp to light a room, you are using electrical energy that comes *indirectly* from living things. Fuels such as coal and oil, produced from living things, are burned and give off energy to change water to steam. The steam runs a turbine that drives a generator, and you have electricity to light the room. About 66 per cent of the energy produced is lost.

The biocell, however, changes chemical energy *directly* into electrical energy. In this process, only about 25 per cent of the energy is lost.

How might a biocell be used? One way is to produce electricity cheaply. The Black Sea might make an excellent fuel source, since its water is rich in the bacteria needed. Dr. Sisler and his team of scientists have already developed a model boat that cruises in a tank of water using electricity generated from the water itself.

Biopower seems to be available from just about any source you can imagine. The United States Bureau of Mines has developed a biocell that uses oxygen from the air as fuel. Other scientists have developed a biocell that uses algae, one-celled plants, as a burnable fuel. Algae, through the process of photosynthesis, can absorb sunlight to change carbon dioxide and water into carbohydrates. The carbohydrates are then used by bacteria as food or fuel. The bacteria change the carbohydrates back into carbon dioxide and water. In this process, the bacteria generate electricity. This system continues as long as solar energy is available. It might be a good source of electricity for space

This do-it-yourself biocell kit uses a sawdust-like material and bacteria for building a twelve-cell biochemical battery.

flights through our solar system, where the sun always shines.

Biocell power packages have been developed to operate ship radio beacons. These models are about the size of automobile batteries and can produce several watts of power.

Work is now under way to use biopower for manned spaceships. In a spaceship, a biocell using algae would change waste materials into air, water, and food for the astronauts. It would also provide electrical energy for operating radios and other equipment.

The biocell is now being developed as a producer of electricity for radios, light bulbs, space capsules, navigation buoys, and other uses. Scientists believe that one day the biocell will produce power at a price that will be the same as that of standard generators. Its big advantage will be that it will use materials that would otherwise be nothing but waste. If biocells can be operated on sea water, sawdust, air, sunlight, and sewage, we may have an almost inexhaustible source of energy. We would no longer be dependent on fossil fuels, such as coal and oil, that we use today. Science for tomorrow's world may use energy from living things—biopower.

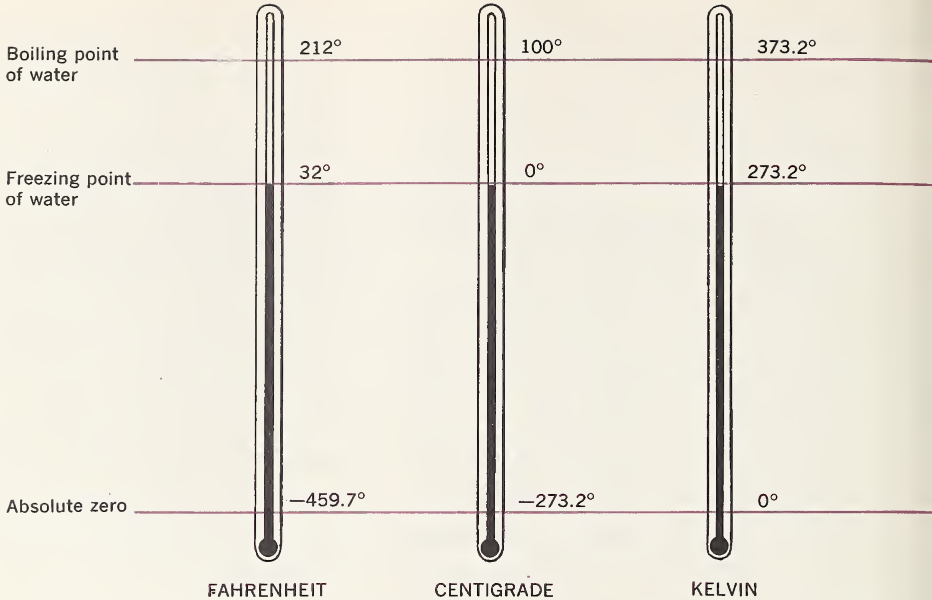
Cryogenics—The Supercold World

A few years ago, some scientists slowly lowered a metal ball over the center of a metal ring. As the ball was lowered it seemed to become lighter and lighter. Suddenly, it stopped its movement downward and floated just above the ring—with no visible support.

The scientists said the ball could float there forever. Quite a trick? It is only one of the many unusual things that can take place in the supercold world of **cryogenics** (kry-oh-JEN-ikss). *Cryogenics* comes from two words—*kryos,* for "icy cold," and *generare,* which means "to make."

The science of cryogenics deals with temperatures near absolute zero—minus 459.7° F., or minus 273.2° C. Over a hundred years ago, the British physicist Lord Kelvin stated that, according to his mathematics, at these temperatures the molecules of which matter is made would theoretically stop their motion. This point, said Lord Kelvin, would be absolute zero.

How cold is absolute zero? The lowest natural temperature recorded is minus 126° F., in Antarctica, and this is over 300° warmer than absolute zero!



This illustration shows three scales of temperature measurement.

Superconductivity

The experiment with the metal ball demonstrated the phenomenon of **superconductivity** (soo-per-kon-duk-TIV-uh-tee). This is a characteristic of certain metals when they are cooled to near absolute zero.

To learn more about superconductors we must go back over fifty years to the work of Heike Kamerlingh Onnes, a Dutch physicist. In 1913, Onnes won a Nobel Prize for producing the coldest temperature that was known to man—minus 272° C., or almost absolute zero.

Onnes went on to discover that once he started an electrical current in supercold mercury, electrons continued to move around the circuit without ever stopping. He did not know why this occurred, nor did anyone else. But scientists since then have found many other superconductive materials.

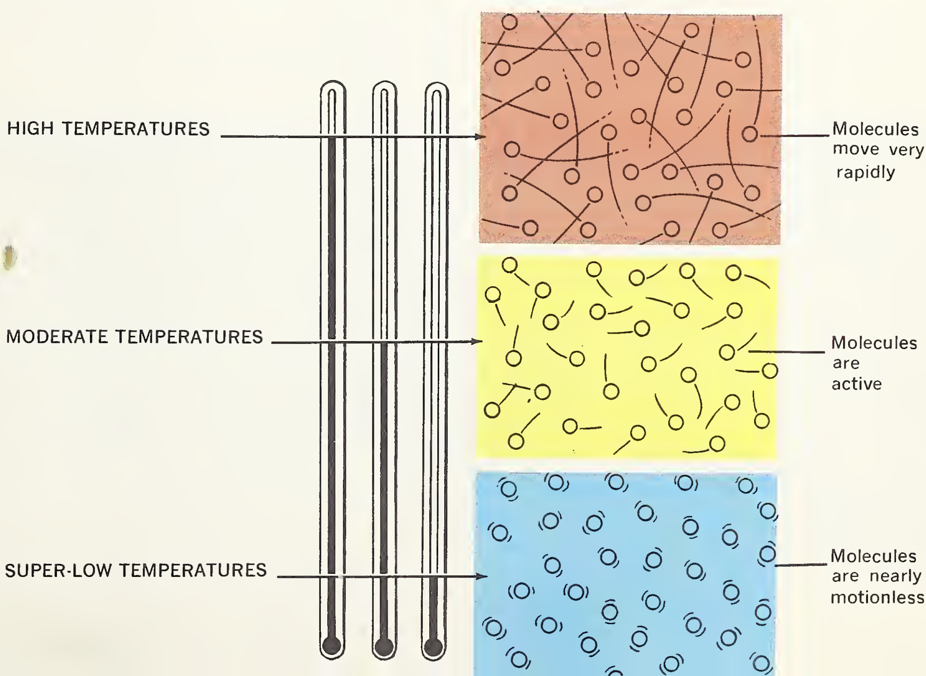
Materials such as lead, aluminum, uranium, and titanium can become superconductors. At temperatures a few degrees above absolute zero, electricity meets no resistance in these materials, and the current seems to circle endlessly in the circuit.

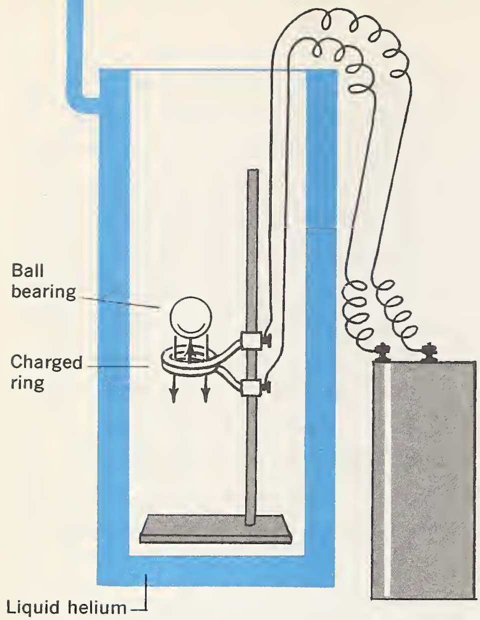
Superconductors as Magnetic "Mirrors"

Later discoveries showed another strange phenomenon of metals in a superconducting state—they *repelled* a magnetic field. The explanation is that a magnetic field builds up certain "currents" in the metal. These currents create an identical, and therefore opposing, magnetic field. Superconductors are in effect magnetic "mirrors." To understand this effect better, let us go back to the ball-and-ring experiment. Both the ball and the ring were cooled to the point where they had become superconductors. A current was set up in the ring, creating a magnetic field around the ring. As the ball was lowered, the magnetic field in the ring built up currents in the ball. The ball produced its own magnetic field, which repelled that of the ring—just as like poles of bar magnets repel each other. The result of the experiment was that the ball floated above the ring.

How might scientists apply this phenomenon? They can produce a frictionless bearing. A bearing is used to

This diagram shows the effect of heat on metals. Electricity does not flow well through metals at high temperatures. Electricity will flow well through certain metals such as silver and copper at moderate temperatures. Electricity flows very well through certain metals such as lead and tin at super-low temperatures. What relationship is there between the movement of molecules through a metal and the flow of electricity?





The ball and the ring were cooled to the point where they became superconductors. What happens when a current is set up in the ring?

support or guide moving parts. It is the part of a machine which *bears* the friction when the parts are in contact and moving. The ball bearings in roller skates greatly reduce the friction produced by the turning wheels. Look at a pair of skates and you will see how they work. Notice that the bearings are in contact. Friction produced by the wheels is less than if there were no bearings. A superconductor bearing would have no physical contact between surfaces. Such a system is superior even to air bearings, since the superconductor can function in a vacuum and eliminate the drag even of air.

Because of the remarkable properties of cryogenic superconductors, devices have been developed that include generators, magnets, motors, switches, transformers, and computer parts. Can you tell how cryogenic superconductors might be used in each of these devices? How would you go about finding the answer to this question?

Superfluids

Just as some metals can become superconductors, some liquids can become **superfluids** at cryogenic temperatures. These superfluids show some unusual properties. One of these properties is known as "creep." Liquid helium, for example, creeps up and over the walls of its container, and finally empties itself from the container. You can see this happening in the picture on the next page.

At a few tenths of a degree above absolute zero, oxygen and nitrogen change from liquids into solids, looking like snow.

Cryogenic liquid oxygen and other gases are being used in liquid-fuel rockets. Liquid oxygen is also being used in place of high-pressure tanks of oxygen gas in the storage of breathing oxygen for aircraft and submarines. Can you tell what advantage the liquid oxygen has over the high-pressure tanks?

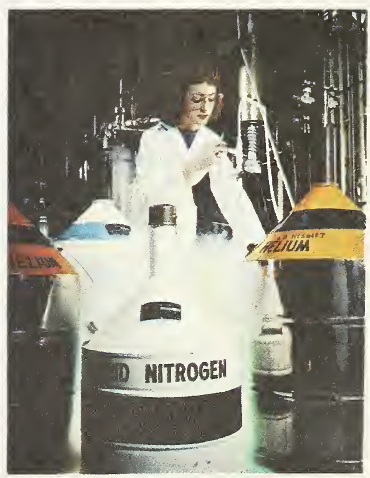
Other Uses for Cryogenics

The science of cryogenics enables scientists to produce the temperatures of outer space, which may be close to absolute zero, so they can try to develop better fuels and new metals that are able to withstand these temperatures. Cryogenics also permits scientists to build better electronic and other equipment needed for guiding space flights.

Cryogenics has also branched out into **cryobiology**, for work with living tissues, and **cryosurgery**, in which operations such as repairing the retina of the eye are performed with probes cooled by liquid nitrogen.

Cryogenics holds great promise as a part of tomorrow's world.

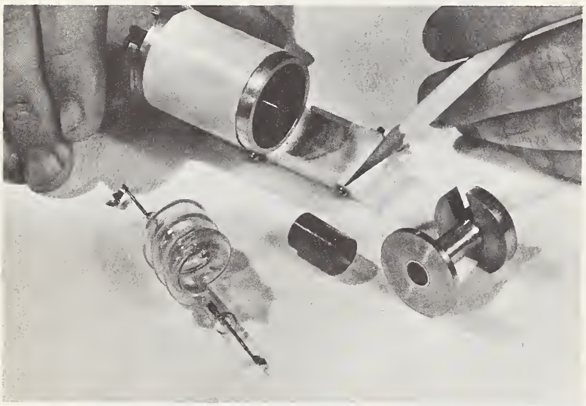
In each picture you see the phenomenon known as "creep." On the left, a scientist experiments with superconductivity to create very strong magnetic fields. How do technicians who work with liquid gases for rockets protect themselves?

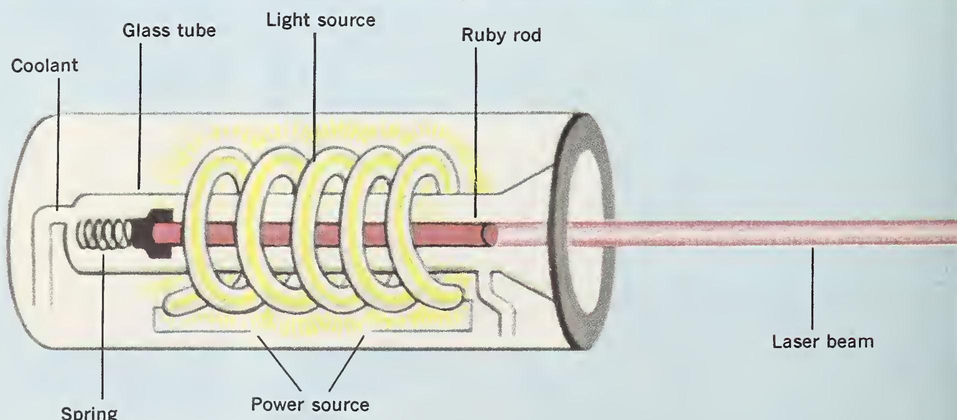


Lasers—Light Brighter Than the Sun

A ruby rod about half the size of a pencil is bathed in bright light coming from a coiled glass tube of xenon gas. The tightly packed atoms in the ruby are excited by the light, which they amplify into an intense beam. This beam is the **laser,** developed by Dr. Theodore H. Maiman in 1960. The word *laser* is made up of the first letter of each word in the name: *l*ight *a*mplification by *s*timulated *e*mission of *r*adiation.

Dr. Theodore H. Maiman studies the equipment needed to produce a laser. Below, you see a diagram of the materials used to produce a laser. You can get an idea of how small the parts of a laser are by looking at the picture on the left.





The laser is far brighter than the sun. Lasers can burn holes through diamonds, bounce beams off the moon, transmit television pictures, weld metals, perform surgery on the human eye, and kill cancerous growths. Because lasers can travel for great, great distances, they can seek out galaxies at the edge of the knowable universe. Possibly they may be used as a means for human beings to communicate with the creatures of other worlds—if they exist.

A Laser Moonshot

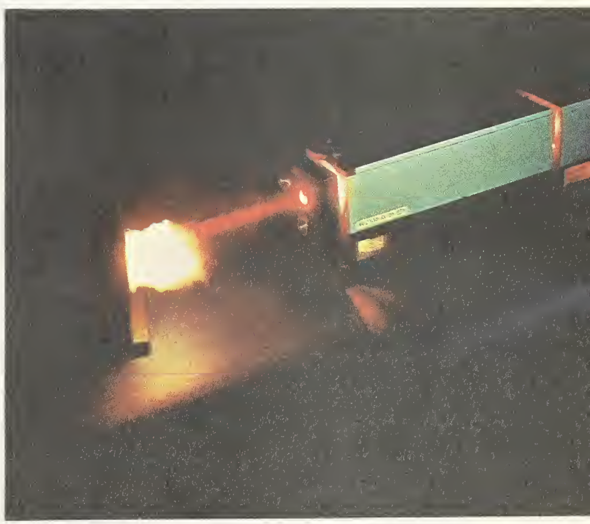
The laser beam goes in only one direction, unlike the beam of a flashlight, which fans out and is cone-shaped. A flashlight's beam is a steadily enlarging cone, as shown in the picture.

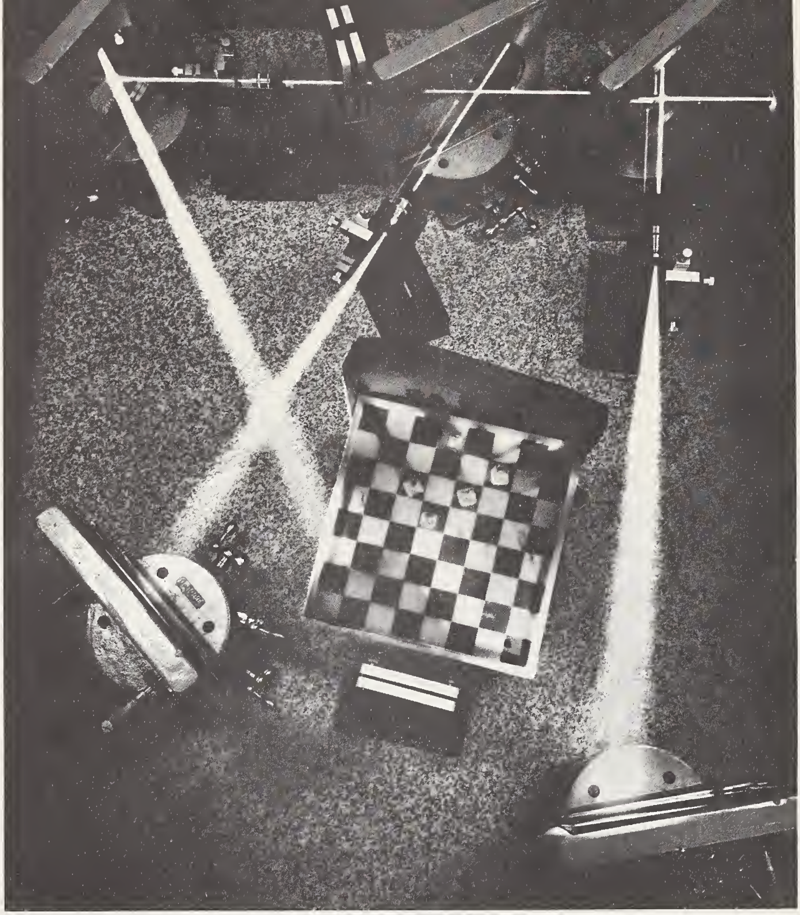
Searchlights send out their light in ever-widening beams, as do flashlights. If a searchlight beam were powerful enough to reach the moon, its light would cover a circle 25,000 miles in diameter. Can you tell why a searchlight beam cannot be reflected back to earth from the moon?

In 1962 scientists at the Massachusetts Institute of Technology fired a laser burst at the moon. The beam that hit the lunar surface was only a *few* miles in diameter and was reflected back to earth. The narrow beam of the laser is one of its most important properties. In this narrow beam is a tremendous concentration of energy. This is why it can burn holes in diamonds.

The searchlight's beam widens in a cone.

Notice the narrowness of the laser beam.





Lasers have been used to take photographs. Here you see laser beams set up to take photographs of a chess game.

Other Uses for Lasers

The laser may play a role in electronic computers. Research is under way to make circuits using light beams instead of wires. To join separate computers thousands of miles apart, telephone lines or radios are now used, but laser "light pipes" may one day take their place.

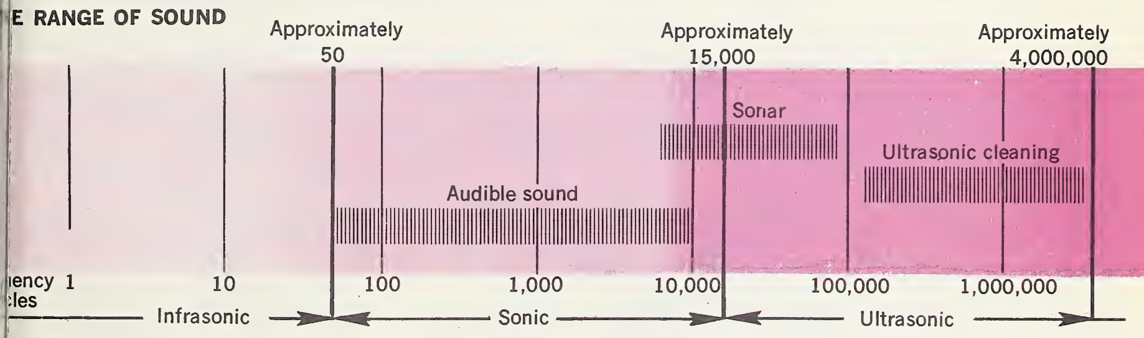
The laser is a scientific achievement that in a short span of years has become one of the most exciting new instruments in scientific research for tomorrow's world.

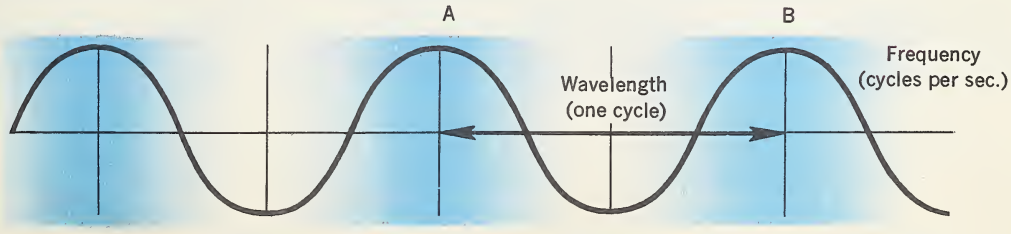
Ultrasonics—The Sound You Cannot Hear

Imagine washing dishes and clothes with sound, making scrambled eggs right in the shell with sound, or perhaps tenderizing food or cleaning watches and surgical instruments with sound. These are just a few of the many uses for ultrasonics—the silent sound.

What is silent sound? Have you ever used a dog whistle? If you have, you know that *you* cannot hear the whistle. Yet your dog must, because he reacts when you blow it. So we know there are sounds that we cannot hear. **Ultrasonics** is based on the same principles as those of the sound waves we can hear. Sound, as you have learned, is a vibration that takes place in a medium such as air, water, or solid material. The vibrations make a wave that passes through the material without causing the material to move. Man's ears are sensitive to certain vibrations. The sound we hear lies in the range of 16 to 20,000 cycles per second. Above and below that range is ultrasound.

Sound is measured by its frequency, which is given in cycles per second. A cycle is one complete wave. If a sound wave has a frequency of 15,000 cycles per second, this means 15,000 waves pass a given point each second. If the frequency is less, fewer waves pass the given point in a given time. Wavelength is the distance from any point on a wave to the same point on the next wave, as from A to B. The more rapidly something vibrates, the higher the frequency and the shorter the wavelength. Can you tell why?





Focusing Sound Waves

Just as light waves can be focused, so can sound waves. Listening devices using reflectors can focus sound. Sound can be both reflected and focused. The science of ultrasonics uses these properties of sound in devices such as microscopes and telescopes that use sound waves instead of light.

Sound waves also affect the material they move through. For example, jet planes have caused sonic booms, which have cracked windows and damaged buildings. Sonic boom is caused as sound waves pile up ahead of jet planes as the planes travel faster than the speed of sound.

The Advantage of Ultrasonics

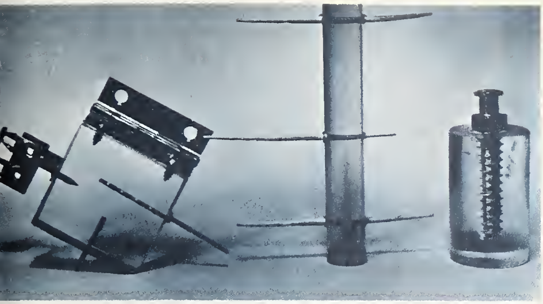
Why do we not use the sound we hear rather than ultrasonics? One important reason is noise. If the power needed for ultrasonic devices could be heard by human beings, it would probably drive us out of our minds and perhaps harm us in other ways. The advantage of ultrasonics is that the sound cannot be heard.

Ultrasound has been used in the sea to find enemy submarines. *Sonar,* which stands for *so*und *n*avigation *a*nd *r*anging is a device that sends out sounds underwater from a boat at regular intervals. The sound moves through the water until it strikes the

This machine cuts by means of ultrasonics.

bottom—or a school of fish, a submarine, or something else that is solid. Part of the sound is reflected and picked up aboard ship on the device. Since the speed of sound through the water is known, it is easy to measure the distance to the object by the length of time it takes for the echo to return to the ship.

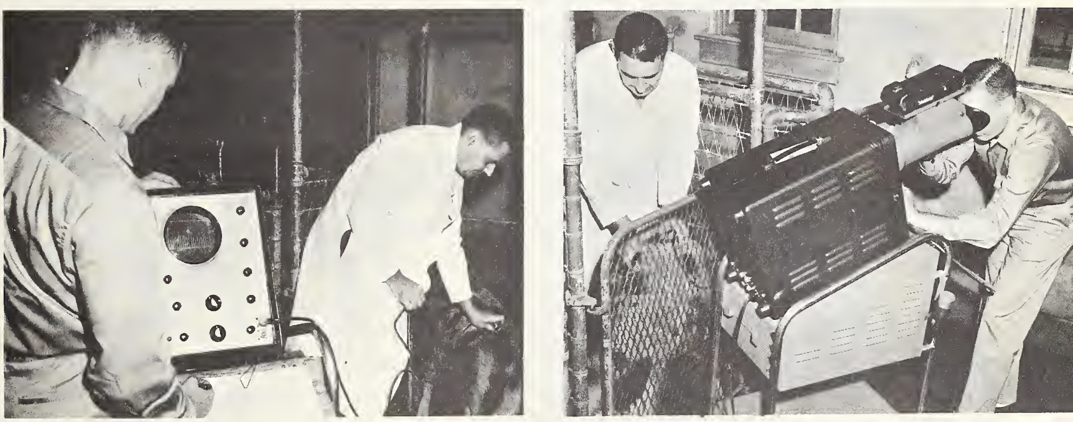
This reflection idea is also used on land. Are you able to tune your



These parts have been put together using ultrasonic methods.

television set by means of a wireless remote control? It is probably an ultrasonic device. Some automatic garage doors respond to an ultrasonic whistle on a car. Ultrasonic alarms can be used to spot faulty products on an assembly line. These alarms can also be used in buildings to detect rats or burglars. Ultrasound is used to find faults in metal, glass, and rubber parts. It can measure the flow of liquids in closed tanks. Ultrasonics can also be used to assemble the parts of instruments. The photograph on the left shows some completed instruments. Can you tell how sound was used to assemble them? Ultrasonic cutting and grinding tools and drills are used on hard-to-work materials. One such device is shown on page 364. Ultrasonics has been used to homogenize peanut butter and tenderize meats and frozen foods. Ultrasonic devices also check cattle for their content of lean and fat. Two ways in which such devices are used are shown below.

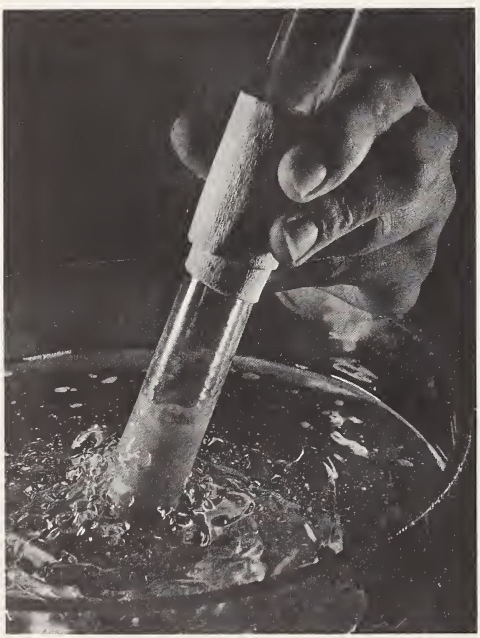
Scientists use an ultrasonic device to measure back fat on a live hog. On the right, such a device is equipped with a camera to make a photographic record of the tissue depth.



Cleaning with Sound

Ultrasonic equipment can create a churning effect in water. This effect is used to clean things in tanks by producing heat. Everything from watches to hypodermic needles can be cleaned better than ever before with ultrasonic cleaning. Test models of ultrasonic dishwashers and clothes washers have been made. They have proved to be successful. The problem now is to bring down their cost so that they can be used in homes.

Ultrasonics is used to stir and mix two substances, such as water and mercury, that under ordinary conditions do not mix.



Ultrasonics in Medicine

Medical scientists have used ultrasonics to relieve pain from arthritis and other ailments. They have also used ultrasonic methods to soften scar tissue around joints so that it can be flexed almost normally.

The ultrasonogram, a picture taken with sound, is being used to diagnose illnesses in the way that X rays are used. There are advantages over X rays. First, there is no danger from radiation. Second, the soft tissues of the body can be "seen." X rays do not show the soft tissues as well as they do hard (bone) tissue. Ultrasonograms are not so sharp as X-ray pictures, but improvements are being made. One day we may have ultrasonic microscopes that will be capable of showing us objects more clearly than light microscopes can.

Other Uses for Ultrasonics

Experiments are now being done on using ultrasound to remove soot and fog from the air. Chasing away unwanted birds, harmful insects, and other pests is another way in which ultrasonics is used.

On the left, you see another use for ultrasonics.

The possibilities for the use of ultrasonics seem as limitless as the scientist's and the engineer's imagination.

Using What You Have Learned

1. As you read about the new branches of science, were you aware of how many areas of science were brought together in each new branch? For example, bionics brought together biology, electronics, chemistry, and physics. What fields does the laser combine? What fields does ultrasonic research bring together?

2. Some other new developments in science are the solar battery, electronic computers, and ground-effect machines. Find out about each of these developments, and write a report on them. What are some good ways to find out about new developments in science?

3. Make a sign that reads *Science—Today and Tomorrow*. Place the sign on your classroom bulletin board. On this section of your bulletin board pin newspaper and magazine clippings of new science developments. Change the display each week. Perhaps you will have room enough to divide the board into sections for biology, chemistry, geology, physics, and any other areas that interest you.

You and Science for Tomorrow's World

You have now read about five new branches of science. You will learn more about these and other new branches as you go further in science in school. You will also find out more from books, newspapers, television, and radio. As you go further in science, you will find that all the science information you learned in your earlier school grades is necessary for you to understand what is happening today and what will be happening tomorrow in science. For example, you need to understand light before you can understand the laser. And you need to know the properties of sound before you can understand ultrasonics. The science you are now learning is helping to prepare you for the science for tomorrow's world.

Why Study Science?

Many of you will not become scientists, and you wonder why you should study science. The answer is simple. No matter what career you decide on, your knowledge of science will enable you to understand better the world in which you live.

We live in an age of science. Science can provide us with marvelous tools for the solution of many of the problems of both our physical and our social world. The work of scientists shapes the life of every human being on the earth. It will affect the future of generations to come. Both our lives and our livelihoods depend very greatly on science.

The Place of Mathematics in Science

If you are interested in any scientific field, whether it is wildlife management or nuclear physics, you will need to study mathematics. You cannot get along in any area of science without mathematics.

You may remember that in the fourth grade you learned that scientists use mathematics in comparing things. In the fifth grade, you learned about the theory of probability and how the scientist uses it in testing ideas. Again you needed mathematics. Earlier you learned that one important way of the scientist was measuring things, and again you needed mathematics to help you understand. Do you now see why mathematics is essential to the understanding of science?

The Science Team

The six men in the picture are all members of a research and development team that produced an improved X-ray system. This system produces sharp images even though the amount of time a person is exposed to radiation is 80 per cent less. The new system will enable radiologists (X-ray specialists) and others to do a much better job of medical diagnosis. But the really interesting thing about this story is that not one of the six men was trained in medical science.

These experts work at General Electric's X-ray Department in Milwaukee, Wisconsin. There are a physicist, an electrical engineer, an industrial designer, an economist, and a mechanical engineer among the six. When they were your age, they did not know where their studies would lead them. Even when they were in college they had no idea they would someday help to advance medical progress.

There are thousands of such teams in industry, research, and government. Their projects range over designing and launching spacecraft, building an arti-

These six men, all trained in different fields, worked together to develop the X-ray system shown. Many kinds of training are needed for today's science.

ficial heart, and developing toothpastes to prevent cavities.

Because so much is being learned about the world in which we live, a team of specialists in different fields is needed to work on most research projects.

Careers in the Biological Sciences

Biologists may work in the country, in the city, in a university, in an industrial plant, or in a hospital, among other places. Their work is as varied as the forms of life found on earth. Some biologists work in laboratories, using microscopes and test tubes, surrounded by animal cages, flower pots, or cultures of microorganisms. Others can be found on oceanographic vessels exploring the oceans. Still others may be found tracking rare animals and plants in the jungle or the Arctic, or exploring fields and woods.

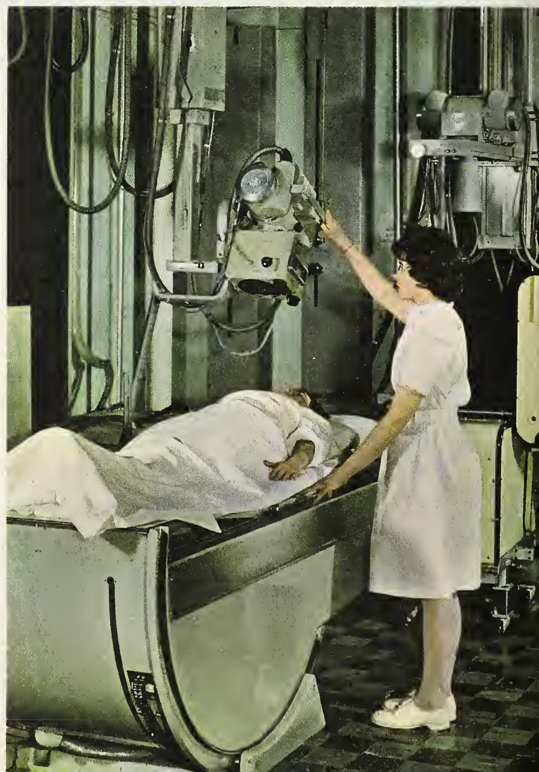
If you like working out-of-doors, remember that the United States Fish and Wildlife Service employs many biologists, as does the United States Department of Agriculture, which needs soil

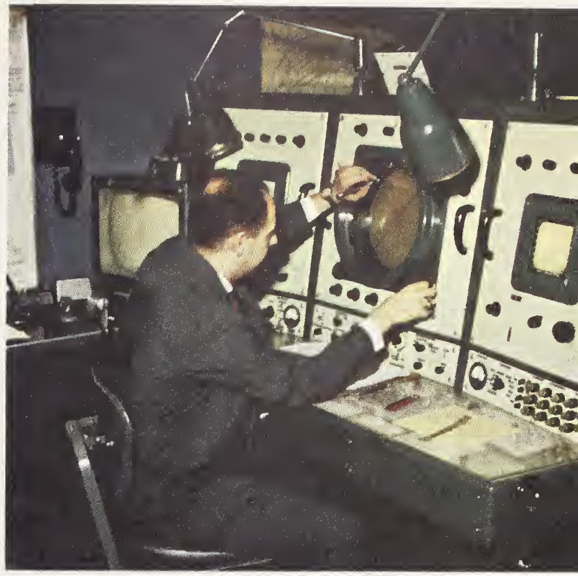
scientists and conservationists. Foresters are needed by government agencies and by lumber and paper companies.

To be a biologist you must have a college education. However, there are also many opportunities if you have a high school diploma and some specialized training. You can become a technician in the biological sciences. A histological technician prepares tissues for microscopic examination. A cytotechnologist examines cells for cancer. A medical technologist carries out chemical, microscopic, and other tests in hospital laboratories. An X-ray technician is trained to take X-ray pictures. You may also become a physical therapist. A therapist, under the supervision of a physician, applies treatments such as exercise, massage, and heat to patients. There is also a great demand for surgical technicians, who assist in hospital operating rooms.

With college training you can become a physician or a dentist or, if you like to care for animals, a veterinarian. If you are interested in drugs, you can become a pharmacist. Perhaps you would like to be a registered nurse—a field open to men and women.

A bacteriologist studies a Petri dish culture. At bottom left, a biologist uses an electron microscope. On the right, a technician prepares to take an X-ray picture.





A radiochemistry specialist measures the radioactivity in a substance. At the right, a meteorologist uses radar to observe certain weather conditions.

Careers in Physical Sciences

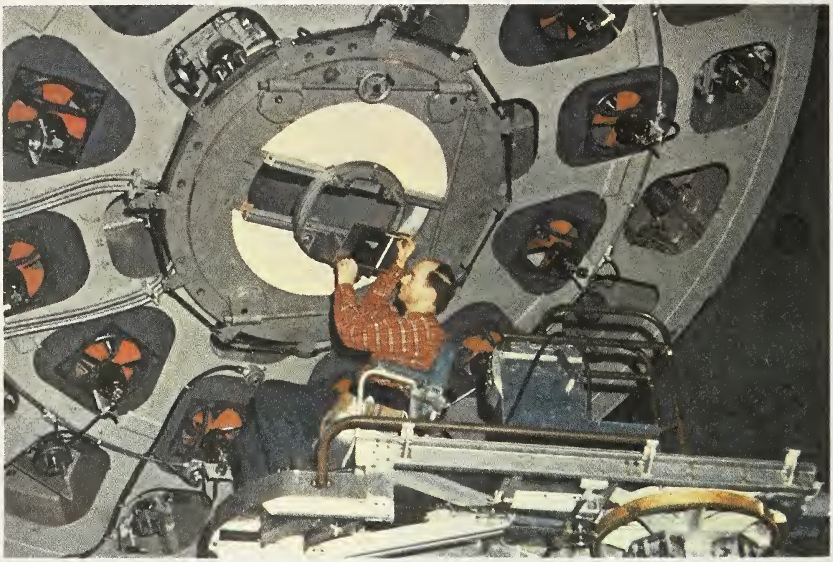
Would you like to work out the direction of a rocket flight as a space physicist? Perhaps you would rather investigate the structure and properties of metals as a solid-state physicist. Or maybe you are interested in being a geophysicist and exploring the earth and its magnetic field. Would you like to work with radioactive substances to discover better ways to fight diseases like cancer? Then you might be very happy as a chemist.

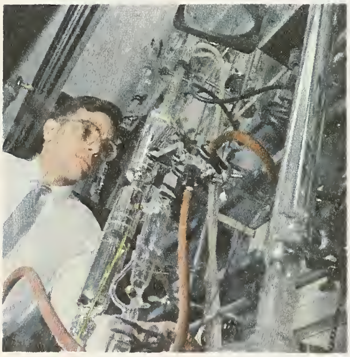
Perhaps you would enjoy studying the oceans, rivers, rocks, and ores. That is the job of the geologist. Exploration geologists use their knowledge to search out valuable mineral and oil deposits. Engineering geologists try to overcome natural obstacles that bar the way for the building of highways, tunnels, dams, and airfield runways.

Are you interested in the weather? Then perhaps meteorology may become your choice. Today's weather watchers are highly trained scientists. Would you rather probe outer space? A career in astronomy offers many opportunities for young men and women.

Physicists, chemists, astronomers, geologists, and meteorologists all must have college educations and usually at least three years of education beyond college. But there are many opportunities in the physical sciences for those who do not go to college.

Next time you watch a rocket flight take-off on television or in the movies, notice how many people are involved. A great many of these people are aerospace technicians, who are not scientists but nonetheless are important members of the scientific team.





An astronomer makes an adjustment on a giant telescope at an observatory. On the left a chemist looks at a maze of glass tubes to see results of his experiment.

A scientist explains a design to aerospace technicians. Each of these men is an important part of the space science team.

An electronics engineer makes a measurement on a satellite he helped to develop. Engineering offers many career opportunities.

Here is a list of just a few careers in the National Aeronautics and Space Administration (NASA): rocket systems firing test technician, optical instrument specialist, scientific photographer, spacecraft inspector, modelmaker, pressure suit mechanic. NASA has many training programs to equip young people with skills for the space program.

Each technician plays a vital role. Without the technician, the world of science would have a difficult time advancing as fast as it does.

Careers in Engineering

The engineer's job is to find usable solutions to problems. He likes to build things and watch them work. There is a great demand for young men and women engineers. And there is a variety of jobs.

For example, would you like to investigate biopower? Biochemical engineers experiment with biocells to find ways to generate electric energy with bacteria. Biomechanical engineers study weightlessness in space, problems

in the design of artificial organs for human beings, and even traffic safety.

Chemical engineers invent the processes for and design, maintain, and operate plants that manufacture insecticides, industrial chemicals, nuclear fuel, explosives, drugs, detergents, and many other products.

Electronics engineers work on a wide variety of problems from designing communications satellites to making phonograph records.

Civil engineers deal with the loads and stresses of the space age, finding out, among other things, how buildings react to sonic boom.

There are many other kinds of engineers. All engineering fields offer a bright future to young people who want to become a part of the advancing frontier in science.

Science-Related Careers

To help those who are not scientists understand the science of today and tomorrow is the work of another team of specialists. This team brings together a knowledge of science and other important fields of interest.

The Science Teacher

One member of this team is the science teacher. He or she has a background in science and in education. His goal is to find new and better ways of helping students to understand science. Because he has a deep interest in science, he tries to arouse such an interest in his students, so that they may become interested in a science career. One of his tasks is to lead youngsters into science careers, for we will need many scientists.

Science teacher Bobby J. Woodruff watches as his students do an experiment. In his classroom, and after class in science clubs, Mr. Woodruff tries to interest young people in science.

Science editor Sidney Seltzer helped to develop the book you are reading. Here he talks with J. Darrell Barnard, one of the authors.

Science writer Earl Ubell reports on science for a large city newspaper. Here he gets firsthand information from scientists.

The Science Editor

A science editor has a background in science, in writing, and in the production of books and magazines. It is his job to bring together experts in many fields of science and education and work with them to develop science books and magazines. A science editor helped prepare the textbook you are reading. He talks with authors and develops outlines, reads the writing produced from these outlines, rewrites and writes material for the books and magazines, and works with artists, designers, and photographers. It is the science editor's job to keep up with the latest happenings in science as well as the latest methods for teaching science.

The Science Writer

A science writer combines a background in science and skill in writing to prepare articles about science for newspapers, magazines, and books. His job is to write about science in a way that people with limited education in science can understand. He travels to science meetings, science laboratories, and universities and meets with scientists to find out about new developments. He may write television and radio stories about events in science. He may write books on science topics for youngsters or adults. Look in your newspaper and in magazines for science articles. Then learn about a well-known science writer.

George Solonovich illustrates many science books. He has an interest in science and in art.

Roman Vishniac is both a noted scientist and a well-known photographer.

The Science Illustrator

A science illustrator draws pictures and diagrams that help explain science principles. This textbook and other science books, magazines, and newspapers use this talent to show and explain things that photographs cannot. An ability to use pictures to explain things and an interest in both science and art are necessary to be a science illustrator. The picture above on the left shows a well known science illustrator at work.

The Science Photographer

When a record is needed of the way amebas reproduce, for example, a motion picture or a series of photographs may be made. Such work demands special techniques and a knowledge of the subject. Many times, the science photographer is both a scientist and a photographer. He uses his talents as a photographer and his knowledge of science to film scientific occurrences. The field of science photography will offer many opportunities in the future.

The Science Information Specialist

The five careers you have just read about provide science information. This information takes the form of books, newspaper articles, magazine stories, technical papers, films, filmstrips, records, and tape recordings. Every year millions of technical reports and thousands of books and audiovisual aids are produced. How can all these be stored so that they are available when needed by scientists, students, and other interested people?

This is the task of the science information specialist, who seeks better ways to store information and to locate such information quickly when it is needed. A knowledge of science and library work makes the information specialist an important person for the scientist seeking specialized information or for the student writing a paper on a famous scientist.

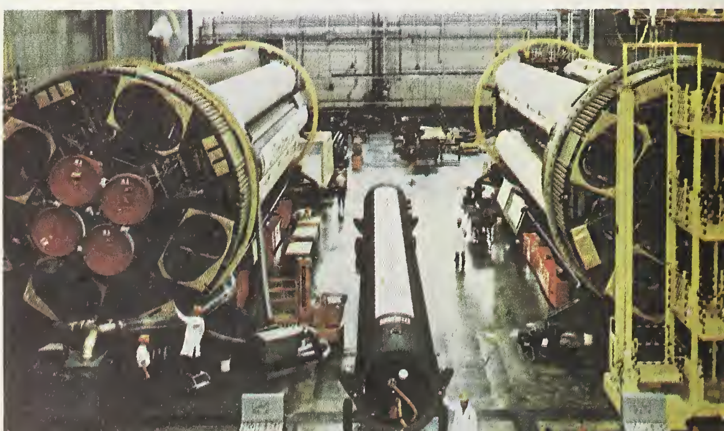
Science information specialists are trying to find new ways to store science information.

The team of people you just read about brings you the work of the scientist in words and pictures that you can understand. Their careers show how an interest in science and an interest in another subject can be combined. There will be many opportunities for careers in these fields. Every year, more and more teachers, editors, writers, illustrators, photographers, and information specialists are needed.

The Science Team in Action

Today science is a field of specialists. A biologist may specialize in virology, zoology, bacteriology, ecology, botany, or biochemistry, among many other areas. A physicist may specialize in nuclear physics, chemical physics, solid-state physics, geophysics, or biophysics, among other fields. The same degree of specialization is possible for engineers. Today's scientists find many ways to use their special interests and abilities. Curiosity leads them. And so it is not strange to find chemists, physicists, and biologists working on the same project.

Thousands of men and women are needed to launch just one spacecraft into outer space. This means many people with many talents and skills must work together. Food must be prepared, models must be made, rockets must be manufactured, and experiments must be conducted. The work does not end with a launching. Each mission brings back information that must be studied. The results may be that new and better ways of doing certain things have been discovered, or that adjustments have to be made, or that it is necessary to start all over again because something did not work properly.



In June, 1965, six United States scientists—two medical doctors, one geologist, one physicist, one college teacher of electronics engineering, and one teacher of physics—were chosen to train for flights to the moon. Why do you think scientists are needed for future space flights?

If you visit a center for space research, you will find biologists studying the ways in which weightlessness affects the human body. Chemists will be found developing liquid foods. Physicists will be plotting the course and direction of a rocket and determining how long it will stay in orbit. Engineers will be found designing and building rockets. Meteorologists will be studying atmospheric conditions to determine the best time to fire the rocket. Science writers will be preparing stories for magazines and newspapers to inform their readers about what is happening. Science photographers will be taking pictures which will appear in magazines, newspapers, and movies and on television. Aerospace technicians will be busy fueling the rocket, checking its instruments, and manning tracking posts.

All these people have special jobs to do. Without each one's special knowledge and skill, the job of sending a rocket into space could not be done. This interdependence is found not only in space research but also in atomic energy research and cancer research, to name just a few areas.

Teamwork will play an important role in the science of today and tomorrow. But there will always be a place for those who wish to work alone.

Willard F. Libby, Nobel Prize winner in chemistry in 1960, once said, "We scientists are the only people who are not bored, the only adventurers of modern times, the real explorers—the fortunate ones." Scientists are today's real adventurers, but there is also much adventure ahead for those who keep up with science—today and tomorrow.

PLACES OF SCIENTIFIC INTEREST

There are many ways to learn about science. You can read the newspapers daily, and you can read books and magazines about science developments. You can watch special science television programs and listen to science radio programs. You can visit science museums and other places of scientific interest. On pages 386 and 387 you will find a list of such places. On these two pages you will get an idea of what you will find when you visit a museum or a zoo.

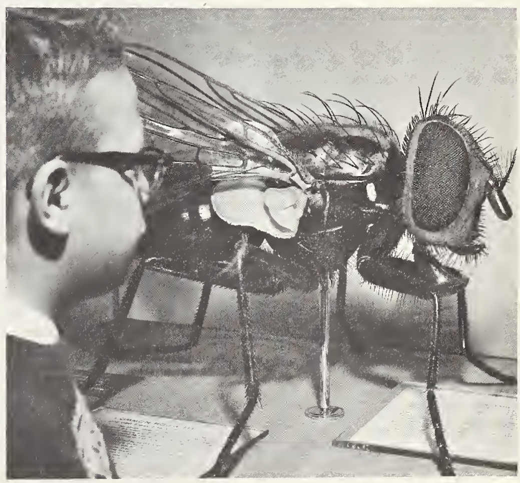
Visitors get a chance to look through a telescope at the Science Museum of the Franklin Institute in Philadelphia.

At the Smithsonian Institution, in Washington, D. C., visitors look at *Freedom VII*, the first United States manned spacecraft.

In 1964, the Hall of Science opened at the New York World's Fair. After 1965, it became a permanent museum in New York City.

Two boys watch a pendulum as it makes a sand pattern at the Boston Museum of Science and Industry. Other children pet a porcupine. One boy studies a giant model of a fly to learn its parts.

At the San Diego Zoo, visitors can walk through a rain forest and see the kinds of birds that live in such an environment.



Using What You Have Learned

Below you will find a list of books and booklets that will give you more information about careers in science.

1. *Scientific Careers in the Agricultural Research Service.* United States Department of Agriculture, Washington, D.C., Misc. Publication No. 798.

2. *Careers in Animal Biology.* American Society of Zoologists, Department of Biology, Goucher College, Baltimore, Md.

3. *Careers for Women in the Biological Sciences.* U.S. Dept. of Labor, Washington, D.C., Women's Bureau Bulletin 278, 1961.

4. *Careers in Biochemistry.* American Society of Biological Chemists, 9650 Wisconsin Ave., Washington, D.C., 20014.

5. *Careers in Botany.* The Botanical Society of America, Department of Botany, Univ. of Texas, Austin, Texas.

6. *How to Decide on Dentistry. New Dimensions in Dentistry.* Bureau of Public Information, American Dental Association, 222 E. Superior St., Chicago, Illinois.

7. *Your Career Opportunities in Medicine* and *Your Career Opportunities in Pharmacy.* Chas. Pfizer & Co., 235 E. 42 St., New York, N.Y., 10017.

8. *Microbiology in Your Future.* American Society for Microbiology, 19875 Mack Ave., Detroit, Michigan.

9. *New Careers in the Health Sciences.* National Health Council, 1790 Broadway, New York, N.Y., 10019.

10. *Careers in Science Teaching.* National Science Teachers Assn., NEA, Washington, D.C.

11. *What Is a Biologist? What Is a Medical Technologist? What Is a Pharmacist?* The Upjohn Co., Box 831, Kalamazoo, Michigan.

12. *Careers in X-ray Technology.* American Society of X-ray Technicians, 16 Fourteenth St., Fond du Lac, Wis.

13. *Careers Ahead in the Chemical Industry.* Manufacturing Chemists Association, 1825 Connecticut Ave., N.W., Washington, D.C., 20009.

14. *Careers in Mathematics.* National Council of Teachers of Mathematics, 1201 Sixteenth St., N.W., Washington, D.C., 20006.

15. *Careers in Atomic Energy.* U.S. AEC, Division of Technical Information Extension, Engineering and Education Section, P.O. Box 62, Oak Ridge, Tennessee.

16. *Physics as a Career.* American Institute of Physics, 335 E. 45 St., New York, N.Y., 10017.

17. *A Career in Astronomy.* American Astronomical Society, c/o J. A. Hynek, Dearborn Observatory, Northwestern University, Evanston, Illinois.

18. *Engineering, a Creative Profession.* Engineers' Council for Professional Development, 345 East 47 St., New York, N.Y., 10017.

19. *Industrial Engineers.* Occupational Brief No. 205, Science Research Associates, 259 E. Erie St., Chicago, Illinois. SRA Occupational Briefs are available in many other career areas.

20. *Careers for Women as Technicians.* U.S. Department of Labor, Washington, D.C., Women's Bureau Bulletin 282, 1961.

WHAT YOU KNOW ABOUT

Science–Today and Tomorrow

What You Have Learned

Of all the scientists who ever lived, 90 per cent are alive today. We live in an age of science, and it is important to be able to understand the world in which we live.

Bionics is a study of living things as systems. With the knowledge gained from such study, scientists and engineers try to copy these living systems and to join living and artificial systems.

The **biocell** is a source of electric energy that makes use of liquid fuels and microorganisms such as bacteria. The biocell obtains energy directly from living things instead of through fossil fuels or chemicals and changes this energy into electrical energy. Biocells are more efficient than other means of creating electric power.

Cryogenics is the study of temperatures near absolute zero: minus 459.7° F., or minus 273.2° C. At these low temperatures, metals become **superconductors.** They also repel magnetic fields. Some liquids become **superfluids** at these very low temperatures.

Lasers give off a very intense beam of light. This beam is very narrow and contains a tremendous concentration of energy. It is far brighter than the sun. This light can be used to bounce signals off objects in space, to carry messages, and so on.

Ultrasonics deals with ultra-high-frequency sounds—sounds that human beings cannot hear. Ultrasonic sounds act in a way similar to light beams. These sounds are used in sonar equipment and to clean materials, among other uses.

Today, science is a field of specialists. Each scientist and science technician contributes his special knowledge and skill to the job he does. There are and will be many opportunities for people to work in science.

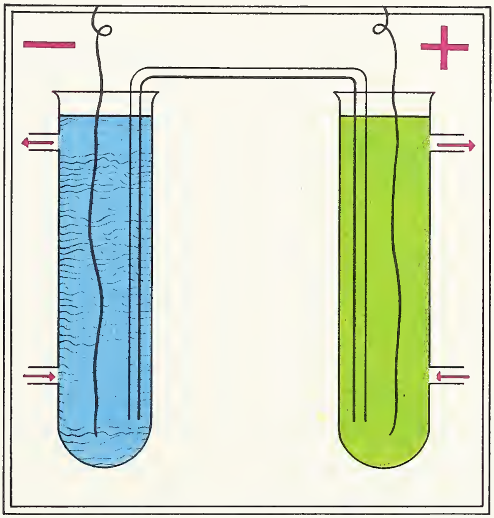
Checklist of Science Words

Here are some science words you read about in this unit. Can you tell what you have learned about each one?

biocell	cryogenics	superconductivity
bionics	cryosurgery	superfluids
cryobiology	laser	ultrasonics

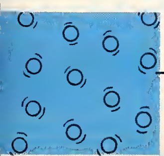
Complete the Diagram

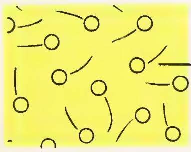
Redraw this diagram in your notebook and fill in the parts needed to make this a biocell.



Can You Tell?

Look at the picture showing the activities of molecules in different metals, and tell for each picture whether the temperature of the metal is high, moderate, or superlow. Also tell whether or not electricity would flow well through the metals at these temperatures.





YOU CAN LEARN MORE ABOUT

Science–Today and Tomorrow

You Can Visit

On these two pages is a list of places of scientific interest. If you do not find a place near your home, ask your teacher or write to your chamber of commerce to find a place near you.

Boston, Mass.
- Museum of Science

New York, N.Y.
- Museum of the City of New York
- American Museum—Hayden Planetarium
- American Museum of Natural History
- New York Botanical Gardens
- New York Zoological Park
- New York Aquarium

Washington, D.C.
- Smithsonian Institution
- Museum of Natural History
- United States Botanical Gardens
- Naval Observatory
- National Zoological Park
- Planetarium, Rock Creek Nature Center
- Kenilworth Aquatic Garden
- National Arboretum

Philadelphia, Pa.
- Franklin Institute
- Franklin Institute Planetarium
- Academy of Natural Sciences
- Fairmount Park Zoological Gardens

Pittsburgh, Pa.
- Carnegie Institute of Technology
- Carnegie Museum of Science
- Hall of Botany, Schenley Park

Chicago, Ill.
- Adler Planetarium
- Brookfield Zoo
- Chicago Natural History Museum
- Museum of Science and Industry
- Lincoln Park Zoo
- Shedd Aquarium
- Morton Arboretum

St. Louis, Mo.
- Missouri Botanical Garden
- Forest Park Zoo
- Forest Park Federal Fish Hatchery

Tulsa, Okla.
- Municipal Rose Garden
- Mohawk Park Zoo

Oklahoma City, Okla.
Stovall Museum, U. of Oklahoma
San Antonio, Texas
Brackenridge Park Reptile Garden
Brackenridge Park Zoological Garden
Dallas, Texas
Museum of Natural History
Health Museum
Aquarium
Marsalis Park Zoo
Houston, Texas
Hermann Park Zoo
Hermann Park Museum of Natural History
Hermann Park Botanical Gardens
San Francisco, Calif.
Maritime Museum
Golden Gate Park
Morrison Planetarium
Museum of Natural History
Steinhart Aquarium
Conservatory
Los Angeles, Calif.
Los Angeles County Museum
Griffith Park
Los Angeles Zoo
Planetarium and Observatory
Palos Verdes Oceanarium
Mt. Wilson Observatory, Pasadena
San Diego, Calif.
Balboa Park
Balboa Park Zoo
Denver, Colo.
Colorado Museum of Natural History
Hawaii
Bishop Museum, Honolulu
Hawaii National Park
Alaska
Alaska Historical Library and Museum, Juneau
U. of Alaska Museum, Juneau
Sheldon Jackson Museum, Sitka
Mt. McKinley National Park
Philippines
National Museum, Manila
Institute of Science and Technology, Manila
Puerto Rico
El Yunque National Rain Forest
England
British Museum of Natural History, London
South Kensington Science Museum, London
British Museum, London
London Zoo
Kew Gardens, London
Montreal, Canada
Maisonneuve Park Botanical Garden
Redpath Museum, McGill University
Montreal Botanical Gardens
Ottawa, Canada
National Museum of Canada
Arboretum and Ornamental Gardens, Central Experimental Farm
Toronto, Canada
Royal Ontario Museum
Riverdale Zoo

Do You Remember?

Green plants are living things that use the earth's materials to make food. Living things get energy from their food. This energy comes from the sun. Living things cannot create new energy; they can only change into other forms the energy that they get from the sun.

Green plants use energy from the sun to make a simple sugar called glucose. The process by which green plants capture and use the sun's energy is called photosynthesis. One product of photosynthesis is oxygen. All oxygen on earth is a result of photosynthesis. Thus all living things—all the animals as well as all the plants—depend on green plants for oxygen as well as for food.

Whenever living things die, their bodies decompose. The material, or matter, in the bodies of these dead plants and animals returns to the soil or to the water and is used again and again. Under ordinary conditions, matter can be changed, but matter cannot be destroyed.

Over millions of years, living things—plants and animals—become adapted to their constantly changing environments. Some animals, for example, *hibernate* during the winter. Other animals *migrate,* or move from places where it is cold in the winter to places where it is warmer. Some parts of the earth's environment have been changed very gradually during the periods of time known as the ice ages. At other times, some parts of the earth's environment were changed very rapidly by erupting volcanoes. The plants and the animals that survived such changes did so because they were adapted to the new environments that were created.

Living things are interdependent. This means that when the balance of nature changes, some living things may die unless a new balance can be reached between the size of their population and the size of their food supply.

Man also lives in nature. But often man does not replace enough of what he takes from nature. Often man does not look ahead. We have been using up our natural resources faster than we are replacing them. It is our responsibility to look toward the future and to plan so that tomorrow's world will have natural resources that are as plentiful as the natural resources that we have today.

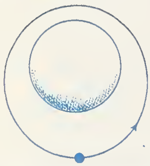
Managing our resources and using them wisely is called *conservation*. We must conserve our fertile soil and find ways to use it to greater advantage. We must conserve our water, keep it clean and safe, and find ways to obtain more of it. We must manage our forests wisely and protect them from man's carelessness. We must find ways to remove the great amounts of industrial and other *pollutants* from the air. We must also prevent our wildlife from becoming *extinct*. Our human resources are our most important resource. We need to find many new ways to encourage and guide young people to build lives that are fulfilling and fruitful.

You can understand much about an animal by observing its behavior, which is the result of the animal's interactions with its environment. An animal's behavior depends in part on the information the animal receives through its *receptors*. Whatever stimulates a kind of behavior is called a releaser. Much can be learned about an animal's behavior by studying its *nervous system,* which *coordinates* the parts of the animal's body. As animals on earth became more complex, so did their nervous systems.

Scientific knowledge is increasing very rapidly. Modern science has helped man to change the way that he thinks about himself and about the world in which he lives. There are many new branches of science and many opportunities for anyone interested in science and science-related careers.

Dictionary of Science Words

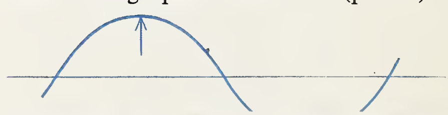
acceleration (ak-sel-er-AY-shun). The increase in speed of a moving object. (p. 20)
accelerator (ak-SEL-er-ay-ter). A machine used by scientists to study the atom. (p. 112)
acclimatize (uh-KLY-muh-tyz). To become used to temperature conditions. (p. 317)
apogee (AP-uh-jee). The point on an orbit at which a satellite (like the moon) is farthest from the object being orbited. (p. 85)



atom. The smallest particle of matter that can be identified as an element. (p. 102)

balanced forces. The different forces acting on an object which cancel each other. (p. 65)
biocell. A battery of bacteria and a liquid fuel. Chemical energy produced by the bacteria is changed directly to electricity. (p. 352)
biochemist (by-oh-KEM-ist). A scientist who studies the chemical processes that take place in living things. (p. 240)
bionics. The study of living systems to find out what makes them work. (p. 349)

Canidae (KAN-uh-dee). The family of animals that includes wolves and dogs. (p. 330)
carbonic acid (kahr-BON-ik). A weak acid made of water and carbon dioxide. (p. 242)
Centigrade scale. A system of measuring temperatures in which the temperature of freezing water is zero degrees and the temperature of boiling water is 100 degrees. (p. 55)
central nervous system. That part of an animal's nervous system that consists of the brain and the spinal cord. (p. 325)
charge. An electrical charge is the quantity of electricity possessed by an object. (p. 110)
chemoreceptors (kem-oh-rih-SEP-terz). Those parts of an animal's nervous system that are stimulated by chemicals. (p. 308)
chlorophyll (KLOR-uh-fil). The chemical that enables plant cells to change carbon dioxide and water into sugar. (p. 239)
chloroplasts (KLOR-uh-plasts). Green-colored parts of plant cells. The chloroplasts make chlorophyll. (p. 240)
comet (KOM-it). A body, made up of rocks and gases, that orbits the sun. (p. 89)
conduction (kun-DUK-shun). The movement of heat or cold from one object to another of a different temperature. Also, the movement of electricity through a wire. (p. 50)
conductor. Any substance through which an electric current will flow easily. (p. 118)
conservation. Wise use of resources. (p. 267)
coordination. The ability of different parts of the body to work together. (p. 324)
corpuscles (KOR-puss-'lz). The name given by Newton to the particles that he believed carried light through space. (p. 194)
crest. The high point of a wave. (p. 221)



cryobiology. The study of living tissues that are at very low temperatures. (p. 359)
cryogenics (kry-oh-JEN-ikss). The science that deals with temperatures near absolute zero. (p. 355)
cryosurgery. Surgical operations in which super-cooled instruments are used. (p. 359)

demagnetize. To remove magnetism. (p. 131)
diffraction (di-FRAK-shun). The bending of light as it passes a sharp edge. (p. 216)

diffusion. The process by which molecules move from an area where there are many to an area where there are fewer. For example, molecules of a drop of ink will diffuse in a cup of water. (p. 41)

electron. A particle that, while rotating on its own axis, is also revolving around the nucleus of an atom. (p. 103)

elementary charges. The charges of electricity that are carried by protons and electrons. (p. 111)

elementary particles. Particles of matter that cannot be further divided. These include protons, neutrons, and electrons. (p. 111)

ellipse (ih-LIPSS). An elongated circle. (p. 84)

English system of standard units. The system that is composed of such units of measurement as the inch, mile, pound, and degrees Fahrenheit. (p. 5)

epicycle (EP-uh-sy-k'l). The orbit of a satellite around a planet that is orbiting around the sun. The orbit of the moon is an epicycle. (p. 150)

epidermis (ep-uh-DER-miss). The covering tissue of a leaf. The outer layer of human skin is also called epidermis. (p. 238)

escape velocity. The velocity a rocket must reach to escape the pull of the earth's gravity. (p. 85)

ethologist (eh-THOL-uh-jist). A scientist who studies the behavior of animals. (p. 301)

extinct animals and plants. Complete families of animals and plants of which there are now no living members. (p. 277)

facets (FASS-its). The separate surfaces that make up an insect's eye. (p. 314)

Fahrenheit scale (FAR-un-hyt). A system of measuring temperatures in which the temperature of freezing water is 32 degrees and the temperature of boiling water is 212 degrees. (p. 55)

Felidae (FEE-luh-dee). The family of animals that includes lions, leopards, wildcats, and domestic cats. (p. 330)

First Law of Motion, *see* **Motion, First Law of.**

formula. A way of explaining ideas in a shorter form. Formulas often use symbols. (p. 14)

frictional forces (FRIK-shun-ul). Forces caused by objects that are rubbing against each other. Frictional forces cause moving objects to slow or stop. (p. 66)

galaxy. A large group of stars, such as the Milky Way. (p. 182)

galvanometer (gal-vuh-NOM-uh-ter). An instrument that detects electric currents in a wire. (p. 100)

gravitational mass. The property of an object that causes the object to be attracted by earth's gravity. (p. 106)

gravity. The force that attracts objects toward the earth's center. (p. 11)

hibernation (hy-ber-NAY-shun). The ability of some animals to sleep throughout the winter. (p. 256)

hypothalamus (hy-poh-THAL-uh-muss). The part of the brain that controls body temperature and appetite in mammals. (p. 326)

inertia (in-ER-shuh). The tendency of motionless objects to remain motionless and the tendency of objects that are in motion to continue moving in a straight line. (p. 106)

insulator. Any material through which electrons cannot easily flow. (p. 118)

laser (LAY-zer). An instrument that generates a very powerful beam of light called a laser beam. (p. 360)

lichens (LY-kunz). Crusty-looking plants that grow on rocks. (p. 242)

light-year. The distance light travels in one year. This distance is 6 million million miles. (p. 176)

magnetic field. The space in which a magnetic force is present. (p. 127)

mass. The amount of matter in an object. It is the mass of any object that causes the object to be attracted by the earth's gravity and to have inertia. (p. 5)

matter. The material of which all objects are made. All matter occupies space and can be weighed. (p. 12)

mechanical receptors. Those parts of an animal's nervous system that are sensitive to pressure. (p. 319)

metric system of standard units. The system of measurement that uses the meter, the kilogram, and degrees Centigrade as standard units of measurement. (p. 5)

Miacidae (my-uh-SIH-dee). An extinct family of animals that lived 50 million years ago, ancestors of the cat and the dog. (p. 330)

migration (my-GRAY-shun). The instinctive seasonal movement of many animals and birds. (p. 256)

mosaic (moh-ZAY-ik) eyes. Eyes that consist of many separate lenses, each of which is separate from the others and transmits its own signals to the brain. (p. 314)

Motion, First Law of. If no outside force is exerted on an object, the object will remain at rest or will continue to move in a straight line at constant speed. (p. 69)

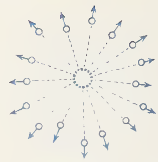
Motion, Second Law of. The rate at which an object changes its speed depends on two things: the mass of the object and the force applied to the object. (p. 77)

neutral atom. An atom that has the same number of protrons and electrons. This means it has exactly the same number of positive and negative electric charges which cancel each other out. (p. 112)

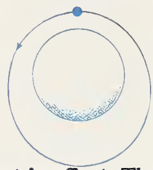
neutron. An elementary particle that is part of the nucleus of an atom. It has no electric charge and has almost the same mass as a protron. (p. 109)

parallax (PAR-uh-lakss). The apparent shift in position of an object when it is looked at from two different locations. (p. 159)

particle theory of light. The theory that light consists of very tiny particles of energy that travel in straight lines. The particle theory explains the fact that light can travel through empty space. (p. 194)



perigee (PEHR-uh-jee). The point on an orbit at which a satellite (like the moon) is nearest to the object being orbited. (p. 85)



photoelectric effect. The creation of an electric current when light strikes certain substances. Exposure meters used by photographers depend on the photoelectric effect for their operation. (p. 101)

photoreceptors. Those parts of an animal's nervous system that are sensitive to light. (p. 312)

pollutant. Any substance that poisons the air and causes harm to living things that breathe it. (p. 274)

polluted air. Air that is contaminated with chemicals and foreign substances. (p. 274)

predator (PRED-uh-ter). An animal that lives by hunting other animals. (p. 255)

protective coloration. The blending in color of an animal's fur or skin with its surroundings so that the animal is difficult to see. (p. 256)

proton. An elementary particle that is part of the nucleus of an atom. The proton has a positive charge of electricity. (p. 109)

protractor. An instrument marked off in degrees that is used to measure angles. (p. 164)

Ptolemaic (tol-uh-MAY-ik) model of the solar system. A model in which the earth is the center of the solar system, and all the other planets, the sun, and the stars revolve around it. (p. 148)

radiation (ray-dee-AY-shun). The giving off of heat, light, or other kinds of energy by the source of the energy. (p. 50)

refraction (rih-FRAK-shun). The bending of light when it enters a different substance. (p. 212)

retrograde motion (RET-ruh-grayd). The backward motion of an object that had been moving forward. (p. 150)

sea level. The level of the surface of the sea. The heights of all land surfaces are based on their distances above or below sea level. (p. 11)

Second Law of Motion, *see* **Motion, Second Law of.**

sensory equipment. The organs containing sensory receptors—chemoreceptors, photoreceptors, thermoreceptors, or mechanical receptors—with which animals receive information concerning the world about them. (p. 307)

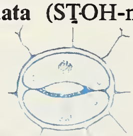
smog. A mixture of smoke and fog that pollutes the air, often causing harm to plants and animals. (p. 275)

social insects. Insects, such as bees, that live together in colonies. (p. 309)

sonar (SOH-nahr). An instrument used to measure distances under water. It does this by measuring the time it takes for a sound to be reflected back from distant objects. (p. 15)

standard units of measurement. Units of measurement that everyone agrees to use. (p. 5)

stomata (STOH-muh-tuh). Very small openings in the leaves of plants, through which carbon dioxide gas can enter. (p. 238)



superconductivity (soo-per-kon-duk-TIV-uh-tee). At very low temperatures, the ability of an electric current to flow through a conductor without any resistance at all. (p. 356)

superfluid. A liquid whose temperature is near absolute zero. Superfluids show unusual properties, such as "creep." Superfluids creep over the walls of their containers. (p. 358)

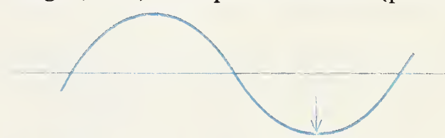
thermal (heat) **energy.** The energy produced by vibrating particles of matter. The vibration is caused by frequent collisions between free electrons and atoms in a conductor. (p. 123)

thermoreceptors. Those parts of an animal's nervous system that are sensitive to changes in temperature. (p. 316)

time interval (IN-ter-v'l). The space between two points of time. (p. 66)

triangle. A closed figure with three straight sides and three angles. (p. 164)

trough (trawf). Low point of a wave. (p. 221)



ultrasonics. The science of sounds whose frequencies are above and below the range of human sensitivity. (p. 363)

vector (VEK-ter). An arrow representing a quantity that has both size and direction. A velocity vector indicates the speed and direction of a moving object. (p. 27)

velocity (vuh-LAHSS-uh-tee). The speed at which an object travels in a certain direction. (p. 26)

volume (VOL-yoom). The amount of space occupied by an object. (p. 11)

wave theory of light. The theory that light travels out in waves in all directions from its source. This behavior can be compared to that of the waves that form in the water when a pebble is thrown in a pond. (p. 217)

Dictionary of Scientists

Bessel, Friedrich Wilhelm. A German astronomer who first measured the distance from the earth to a star. (pp. 24–25)

Carson, Rachel. The American biologist and author who wrote books about nature. She was interested in how pesticides and insecticides might change the balance of life. (pp. 264–265)

Copernicus, Nicolaus. A Polish astronomer who, in 1543, published the theory that the sun, not the earth, is at the center of the solar system, and that the planets revolve around the sun. (p. 153)

Frisch, Karl von. An Austrian zoologist who studies the habits of bees and how they communicate with each other. (pp. 320–321)

Grimaldi, Francesco Maria (grih-MAHL-dee). An Italian scientist who discovered that light bends when it passes through a very small hole. (p. 216)

Herschel, William (HER-shul). A British astronomer who discovered the planet Uranus. (p. 23)

Kelvin, Lord. A British physicist who, over a hundred years ago, stated that molecules of matter near a temperature of absolute zero have theoretically no movement. (p. 355)

Lavoisier, Antoine (an-TWAHN lah-vwah-zee-AY). The French chemist who discovered oxygen. (p. 21)

Leverrier, Urbain (er-BAN leh-vehr-ee-AY). A French astronomer who predicted the existence of the planet Neptune. (p. 23)

Lovell, Sir Alfred Charles Bernard. An English astronomer who studies the stars with radio telescopes. (pp. 180–181)

Maiman, Theodore H. American physicist who, in 1960, developed the laser. (p. 360)

Michelson, Albert Abraham. An American physicist who first measured the speed of light. He won the Nobel Prize in 1907. (pp. 198–199)

Newton, Sir Isaac. An English scientist who discovered the law of gravity, the laws of motion, how planets move, and that light is made up of many colors. (pp. 69, 86–87)

Onnes, Heike Kamerlingh. A Dutch physicist who, in 1913, won a Nobel Prize for producing the coldest temperature known to man —minus 272° C., or almost absolute zero. (p. 356)

Ptolemy, Claudius (TOL-uh-mee). A Greek astronomer who lived about 1800 years ago. He believed that the sun and the planets revolved around the earth. (p. 148)

Sisler, Frederick. An American scientist who, in 1962, developed a biocell that generated enough electricity to power a small radio transmitter. (p. 353)

Thompson, Benjamin (Count Rumford). An American-born scientist who lived in Europe. He discovered how heat behaves. (p. 46)

Thomson, Joseph John. An English physicist who discovered that atoms are made up of even smaller particles. (pp. 104–105)

Checklist of Science Activities

Here is a list of some things you can learn to do as you read this book. At the end of each unit there are four pages that tell you other things you can do.

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